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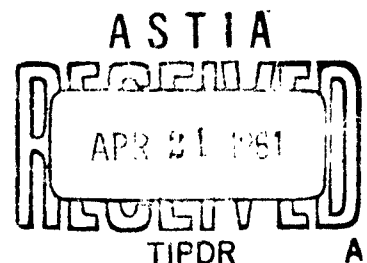


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STANDARDIZATION OF THE SMALL SCALE GAP TEST
USED TO MEASURE THE SENSITIVITY OF EXPLOSIVES

By:
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ABSTRACT: A revised small scale gap test (SSGT) has been developed. It employs a 1.4-inch long, 0.2-inch diameter RDX column loaded in a brass cylinder as a donor. The acceptor is of similar configuration. The sensitivity of the explosive loaded in the acceptor is determined by the test as a function of the thickness of the lucite barrier which is used to moderate the donor output. The mean firing sensitivity, for instance, is determined from the thickness of lucite at which 50% response would be expected. By revision of methods and design, and by careful control of the loading and the testing conditions, the resolution of the revised SSGT has been improved by a factor of 4 to 5 over that of the original SSGT.

PUBLISHED MARCH 1961

EXPLOSIONS RESEARCH DEPARTMENT
U. S. NAVAL ORDNANCE LABORATORY
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NAVWEPS Report 7342

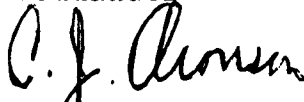
NAVWEPS Report 7342

16 January 1961

A procedure, called the Revised Small Scale Gap Test, has been developed to measure the sensitivity of explosives loaded in small column diameters under heavy confinement. While this procedure is patterned after the original SSGT it differs in the control of loading conditions, in the use of a condensed medium in the gap rather than air, and in the method of assessing response.

The revised SSGT has a 4 or 5 times improved resolution over the original procedure. It thus makes it possible to demonstrate with greater clarity and assurance relationships which are of importance in small diameter explosive systems. This work was carried out under Task RUME 3E012/212 1/F008 10 004 -- Properties of Explosives (formerly 301-664/43006/08, Explosives Applied Research). It should be of interest to workers in the field of explosive sensitivity measurement and to those engaged in the design of explosive trains.

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NAVWEPS Report 7342

CONTENTS

	Page
INTRODUCTION	1
1. Field of interest	
2. Concept of gap testing as a measure of sensitivity	
3. Reasons for revising the SSGT (Small Scale Gap Test)	
APPROACH	1
4. Original version of SSGT	
5. Difficulties inherent in original SSGT	
6. General objectives of revised SSGT	
7. Considerations of design of SSGT donor	
8. Choice of donor loading conditions	
9. Configuration of the gap	
10. Problems involving assessment of actuator response	
11. Steel dent test to be used as criterion of "fire"	
CHOICE OF DONOR EXPLOSIVE.	5
12. Buildup-to-detonation experiments	
13. Buildup-to-detonation results	
CHOICE OF DONOR COLUMN LENGTH	8
14, 15. Factorial experiment (loading pressure, vs. initiator, vs. block type and hardness)	
16, 17. Results of factorial experiment	
18, 19. Basis for choice of initiator and of donor column length	
20. Effect of confinement of initiator on donor initiation	
21, 22. Procedures for controlling column length	
EFFECT OF GAP ON DONOR OUTPUT.	16
23. General idea of experiment	
24. Effect of air and of lucite on output of low intensity donor	
25. Effect of air and of lucite on output of high intensity donor	
26, 27. Dent configuration	
28. Comparison of various configurations of plastic in gap	
THE GAP DECIBANG	25
29. Basis for logarithmic transform	
30. Definition of the DBg	
31. Interpretation of the DBg	
32. Use of DBg in presenting information of Paragraph 25	

NAVWEPS Report 7342

CONTENTS (Cont'd.)

	Page
DONOR LOADING INFORMATION	26
33, 34. Establishing density, length, charge weight, and hole diameter limits	
35. Effect of ram clearance on charge density	
36. Donor body design and procurement	
37. Preparation of donor explosive	
38. "Spring-back" of loaded charges	
39. Charge weight controls	
40. Quality control by measurement of donor output	
ACCEPTOR LOADING INFORMATION	36
41. General consideration	
42. Problem of voids at end of charge	
43. Need and technique for control of density	
CONDUCTING THE REVISED SMALL SCALE GAP TEST	37
44. Firing setup	
45. Firing hints and kinks	
46. Criterion of fire	
47. Statistical procedures	
48. Statistical presentations	
PROOF OF THE PUDDING.	41
49. Data showing increased resolution of revised SSGT	
50. Effect of charge density on sensitivity	
CONCLUSIONS	46
51. Reasons for increased resolution	
52. Considerations involving mechanism of attenuation of donor output	
APPENDIX.	48
RESUME OF EARLY WORK ON THE SMALL SCALE GAP TESTS	
1. General information	
2. Criterion of fire --- burn, expansion, shatter	
3. Loading method	
4. Relationship between diameters of donor charge and acceptor charge on acceptor sensitivity	
5. Density, sensitivity, and fire-criterion relationships	
6. Effect of confinement on acceptor sensitivity	
7. Effect of particle size on sensitivity	
8. Studies of transverse displacement between donor and acceptor	
9. Effect of metal barriers in the gap	
10. Studies involving short column lengths and build-up to detonation	

CONTENTS (Cont'd.)

Page

11. Use of liquid explosives as an acceptor
 12. Measurement of acceptor explosives at high and low temperatures

REFERENCES FOR APPENDIX A	53
-------------------------------------	----

ILLUSTRATIONS

Figure 1. Original Small-Scale Gap Test Set-up	2
Figure 2. Experimental Arrangements for Studying Possible Donor Explosives.	6
Figure 3. Details of P-Plug Loading.	7
Figure 4. Output of Various 0.2 Diameter, Composite High Explosive-Lead Azide Columns in 1.0 Diameter Brass Bodies. 5 Shot Data	9
Figure 5. Alternate Presentation of Results Shown in Fig. 4	10
Figure 6. Configuration of Steel Dent Blocks	12
Figure 7. The Effect of Block Type, Consolidating Pressure, and Initiator on the Output of an Explosive Column	13
Figure 8. Output of Various Length RDX Columns Loaded at 10 KPSI in 1.5 Body, 1.0 Dia	14
Figure 9. A Study of 1.0, 1.2 and 1.4 Long RDX Columns	15
Figure 10. Effect of Gap (Air) on Output of 0.2 Dia Lead Azide Column	17
Figure 11. Effect of Lucite Barrier on Output of 0.2 Dia Lead Azide Column	18
Figure 12. Effect of Gap (Air) and of Lucite Barrier on Output of 0.15 Lead Azide Column	20
Figure 13. Effect of Gap (Air) on Output of 0.2 Dia RDX Column	21
Figure 14. Effect of Lucite Barrier on Dent Output of 0.2 Diameter, RDX Column	22
Figure 15. Comparison of Attenuation by Air and by Lucite	23
Figure 16. Types of Dent, Qualitative Representation	24
Figure 17. Output Attenuation of Revised SSGT Donor by Air	29
Figure 18. Output Attenuation of Revised SSGT Donor by Lucite	30
Figure 19. Effect of Ram Clearance on Charge Density	33
Figure 20. Donor Body Details	34
Figure 21. Donor Loading Details	35
Figure 22. Revised Small Scale Gap Test Setup	38
Figure 23. Diagram of Revised SSGT Setup	39

NAVWEPS Report 7342

CONTENTS (Cont'd.)

	Page
Figure 24. Convention for Presentation of Statistical Parameters	41
Figure 25. Original SSGT Sensitivity of RDX-Calcium Stearate Mixtures	42
Figure 26. Revised SSGT Sensitivity of RDX-Calcium Stearate Mixtures	43
Figure 27. Original SSGT Sensitivity of RDX-Calcium Stearate Mixtures	44
Figure 28. Revised SSGT Sensitivity of RDX-Calcium Stearate Mixtures	45
Figure 29. Effect of Density on Sensitivity	47
Table I. Coefficients of Gap (or Barrier)-Output Exponential Equations for Various Systems	19
Table II. Nominal Dimensions and Manufacturing Tolerances of Lucite Attenuators	27
Table III. Donor Acceptance Limits	31

STANDARDIZATION OF THE SMALL SCALE GAP TEST
USED TO MEASURE THE SENSITIVITY OF EXPLOSIVES

INTRODUCTION

1. Much work has been done towards developing a better understanding of the significant factors which control the transfer of detonation between small diameter explosive charges. One experimental technique which has been developed for this purpose is the small scale gap test.*

2. In the SSGT, the explosive under test is loaded into an axial hole in a heavy walled metal cylinder (the acceptor). A standard explosive charge (the donor) is fired at the acceptor across a gap. It is assumed that the input stimulus at the acceptor will vary inversely with the gap. By applying conventional testing techniques and statistics it is possible to express the probability of initiation (the sensitivity) of the acceptor as a function of the gap.

3. The SSGT has been applied in many different non-standard combinations. Variations have been made in column diameters, column lengths, confinement materials, wall thicknesses, and barrier materials, to mention only some. A resume' of past work using the SSGT is given in Appendix A. So many combinations of test conditions have been used that it is very difficult, if not impossible, to correlate the results with each other or with those of other explosive tests. It is desirable to establish a standard small scale gap test which could be used as a basic tool even in cases where a modification of the test must be made to test a specific explosive system.

APPROACH

4. The original SSGT system is shown in Figure 1. Most frequently it utilized the 0.2-inch I.D. donor and acceptor, brass bodies, air gap, lead azide as the donor explosive, and a firing criterion of "complete shatter". The explanation and significance of the above terms will be given in the following paragraphs.

5. The original SSGT system had a number of limitations. The gap spacing - C - was difficult to obtain with sufficient

* See Appendix A.

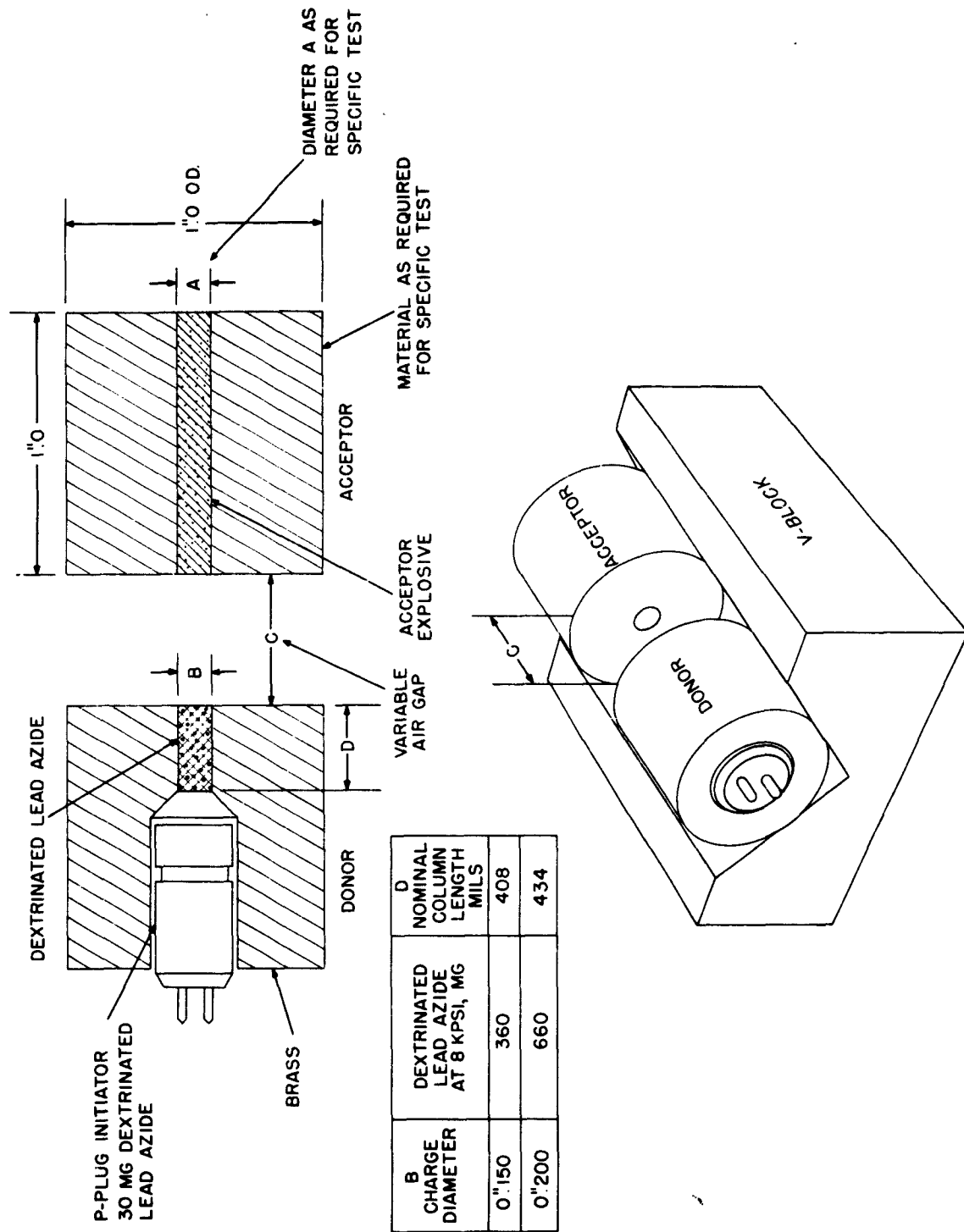


FIG. 1 ORIGINAL SMALL-SCALE GAP TEST SET-UP

NAVWEPS Report 7342

accuracy. The length of donor column - D - was different for different column diameters (due to method of manufacturing and loading) and was not easily maintained even for a single diameter. The output of the donor was too low so that a booster was needed in some cases to initiate the acceptor; this results in two test methods instead of one. A special, non-standard initiator was needed for the system. The method of judging whether or not the acceptor was initiated had a slight aura of wizardry about it.

6. The configuration of the revised SSGT was set arbitrarily, based on a compromise between experiment, experience and expediency. However, the following objectives and arbitrary choices were formulated for establishing the system:

- a. Develop a high intensity output donor.
- b. Donor and acceptors to be 0.2-inch diameter explosive columns loaded into 1.0-inch diameter brass bodies.
- c. Donor explosive column should be chosen such that small variations of column length, weight of explosive, or consolidating pressure will not affect output.
- d. Donor should be high explosive with a separate initiator.
- e. Initiator should be a service item rather than home-made.
- f. Donor output, as measured by steel dent test¹, should be a part of the performance specification and should be checked periodically.
- g. The gap between the donor and the acceptor should be a condensed medium rather than air.
- h. If possible, the steel dent test should be used to measure the output of the acceptor in order to establish the criterion of fire.
- i. If possible, all tests should be run for at least two acceptor explosive densities - 85% and 95% of theoretical maximum density (T.M.D.).

1. NAVORD Report 2422, "Small Scale Dent Test for Confined Charges", 23 April 1952, Warren M. Slie and R. H. F. Stresau.

7. A high intensity, high explosive donor was desirable to put the sensitivity of all explosives into one scale. The loading and handling of the donor would be considerably safer if it were made entirely without primary explosive. Much of the previous SSGT work was done with 0.2-inch diameter explosive columns. The work indicated that most explosives can be initiated at this diameter. In a 0.2-inch diameter column the total charge weight is reasonable from the standpoint of sample weight requirement and blast damage. High charge confinement was obtained by making the O.D. of the donor bodies 1.0 inch and the body material brass. With these bodies machining variations have a minimal effect on explosive behavior, tooling for explosive pressing is very simple, and hydrostatic deformation of the bodies should be negligible for loading pressures up to 35 or 40 KPSI. An initiator capable of slipping into the 0.2-inch ID hole was desired since this would make the test set-up simple to assemble. The Mk 70 and Mk 71 Detonators are two service wire-bridge detonators which meet these requirements.

8. In selecting the length of the donor it was desired that the donor explosive be long enough to build up to "steady-state detonation". Actually a somewhat longer column should be used to minimize the effect of errors in column weight or length. Variations in loading pressures are normally small compared to the variations required to affect the explosive properties of the donor. For example, to go from 80% of voidless density to 95% one might expect to have to increase the pressure from 8 to 10 times. Generally the density varies as the logarithm of the pressure between 2 and 35 KPSI. Since consolidating pressures can be readily controlled to better than $\pm 2\%$, the resultant density should be very closely held. The donor output as measured by the steel dent test was used for deciding on the final donor configuration (column length, density, weight and pressure) and for subsequent quality control of the donor. The donor output must of course be carefully controlled since it is the only common factor in the SSGT.

9. A condensed medium, lucite, was used in the gap between the donor and acceptor as a means of increasing the precision and linearity of the experiment for two reasons:

- a. The gap spacing could be set more accurately.
- b. To reduce the impedance mismatches between donor-to-gap material and gap material-to-acceptor.

10. The SSGT test plan involves some form of go-no go procedure wherein each shot must be evaluated either as a successful initiation or as a failure. Because the preponderance of testing is in the region of marginal initiation it is

NAVWEPS Report 7342

often difficult to decide when a charge has been initiated. The damage done by the donor in the case of a failure may be difficult to distinguish from the effects of a low order explosion in the acceptor. Some arbitrary criterion had to be selected which was consistent with the system. Previously shattering of the acceptor into at least two pieces was taken as a "fire". However, certain explosives have insufficient energy to bring about this shatter even when well initiated. In such cases, in the past, expansion of the extreme end of the acceptor column from 0.20 inch to 0.25 inch or more was considered a "fire". Because different explosives build up to stable detonation at different rates the propagation may not reach steady state in a practical column length, thus complicating the problem. The choice of acceptor body length and of initiation criterion may affect the ordering of sensitivity of an explosive series.

11. The measurement of the vigor of the acceptor by the steel dent test seemed a sensible way to determine whether or not the initiator was successfully initiated; particularly by establishing a "fire" level in a calibrating series wherein the output of overdriven and underdriven acceptors was also measured. It was possible that the presence of the steel dent block at the bottom of the acceptor charge might change the mechanism of acceptor initiation -- an "anvil effect". The magnitude and consequences of the anvil effect, while recognized, did not appear to offset appreciably the advantages of the use of the steel dent block.

CHOICE OF DONOR EXPLOSIVE

12. PETN, RDX, and CH-6 (a pelletizable RDX composition), were studied as possible explosives for the "high intensity donor"*. The experimental arrangements are shown in Figure 2. Brass bodies, 1.0-inch outside diameter by 0.2-inch inside diameter and 1.0 inch or 0.5 inch in length, were loaded with these explosives to 0%, 20%, 40%, 60%, 80%, and 100% of length and the balance filled with dextrinated lead azide. All pressings were at 10 KPSI, the increments being adjusted to be 20% of body length for the high explosive and 0.1-inch long for the lead azide. Eventually three initiators were used: the 30 mg and 142 mg P-Plugs (see Figure 3) and the standard Navy Detonator Mk 70. A sample size of 5 was used for each combination. The outputs of the various explosive combinations were measured by the steel dent test. Because the depths of the dents were

* The term is used to aid in distinguishing this donor from the old dextrinated lead azide donor.

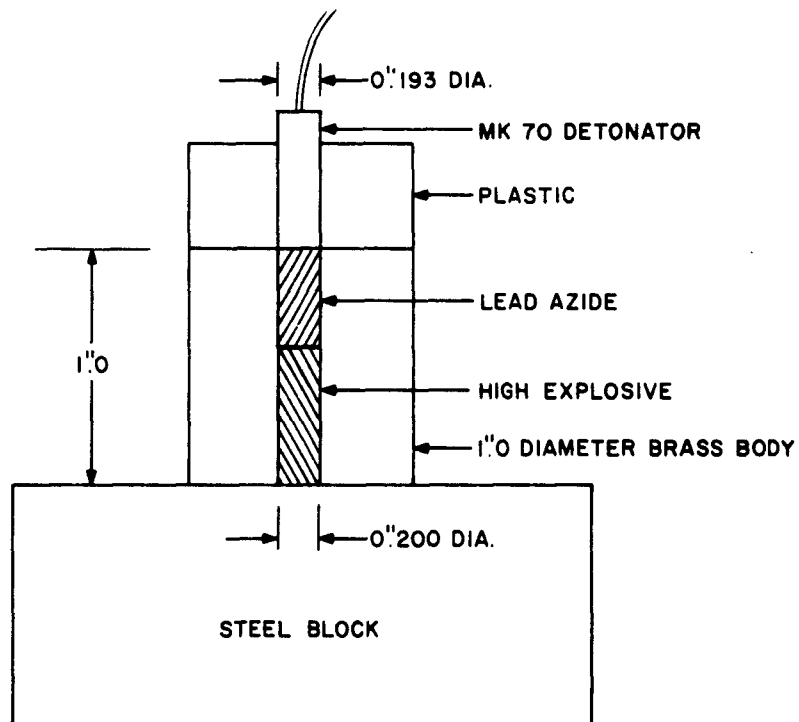
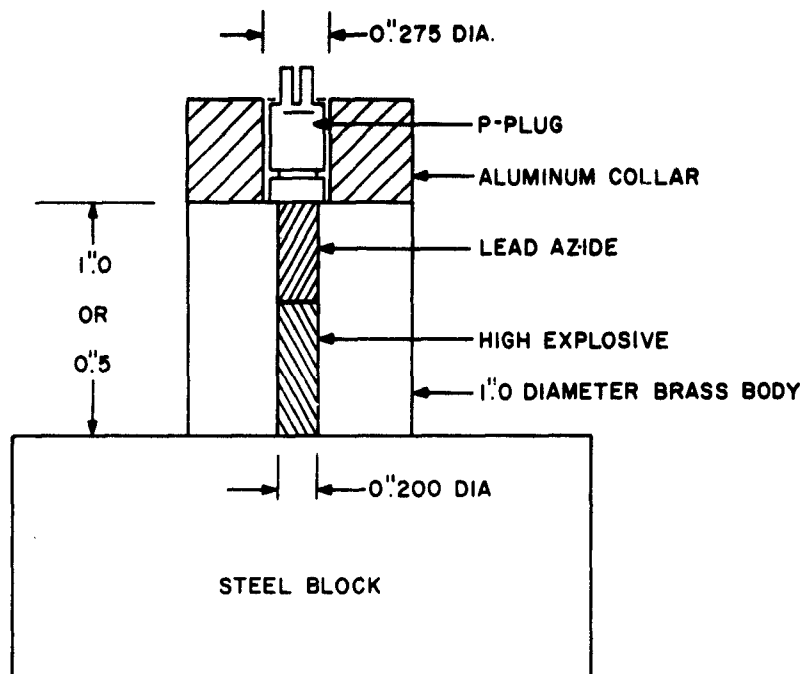


FIG. 2 EXPERIMENTAL ARRANGEMENTS FOR STUDYING POSSIBLE DONOR EXPLOSIVES

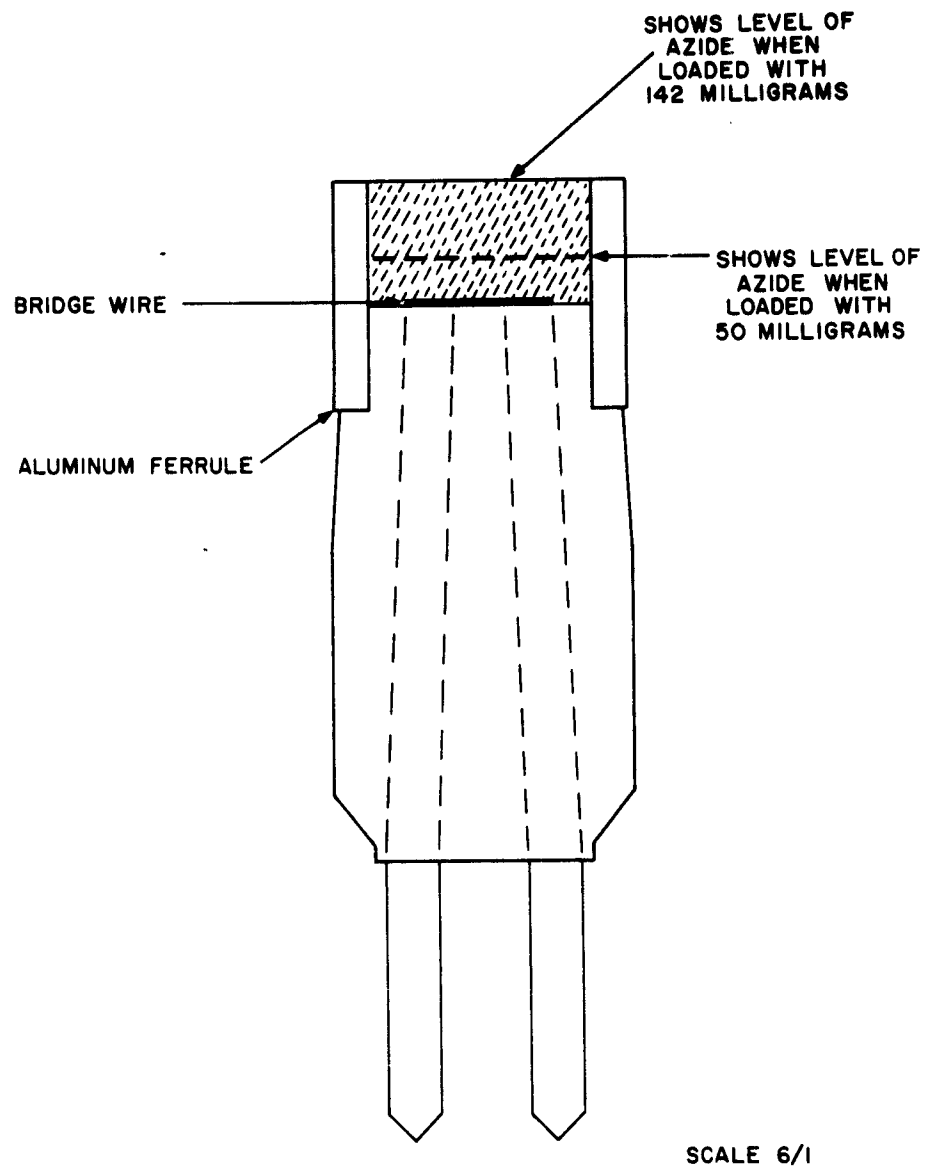


FIG. 3 DETAILS OF P-PLUG LOADING

measured at first by a flat point probe rather than with the sharper point (0"015R) finally chosen as standard, the data have been normalized and plotted in Figures 4 and 5 as relative magnitudes to prevent improper comparison. It was felt (and has been proven by experiment) that the results would be self consistent and that no significant reversals would result because the dents were measured with the flat point. All explosive charges for the SSGT standardization study were weighed. Variability of column lengths and output decreased when loading was changed from "scooping" to weighing.

13. The results of the experiments to standardize the donor (Figures 4 and 5) showed a number of interesting relationships, some predictable and some unexpected. The output of PETN was consistently lower than that of RDX. RDX and CH-6 had essentially the same output. CH-6 was less sensitive than RDX and PETN. While any specific 60% high explosive column* did not appear to exhibit significantly less output than the 80% member of the same group, there was a consistent (and probably significant) trend indicating that the 80% column did have more output than the 60% column. Whether or not this trend would continue at the 100% high explosive column could not be determined by this set of experiments. The results were masked by the difficulty in initiating the 100% high explosive columns.

CHOICE OF DONOR COLUMN LENGTH

14. At this point in the program, the following decisions were made:

- a. RDX would be used rather than PETN or CH-6 because the output of RDX was higher than PETN and the pure compound was preferred over the mixture.
- b. A 0.8-inch minimum length of RDX would be used in the donor.

15. A factorial experiment was designed to test the effect of consolidating pressure, initiator strength, and steel block on the output of the 0.8-inch long RDX column. Pressures of 10 and 12 KPSI, Detonators Mk 70 and Mk 71, and C and H blocks (see Figure 6) were chosen as the specific factors.

16. The results of the factorial experiment (see Figure 7) show a strong correlation between the dent readings and the block type. There is, however, no basis for judging whether

* A 60% high-explosive column is 0.6 inch long when loaded in a 1.0-inch body; it is 0.3 inch long when loaded in a 0.5-inch body. (Similarly for 80% high explosive columns.) The balance of the column is filled with lead azide.

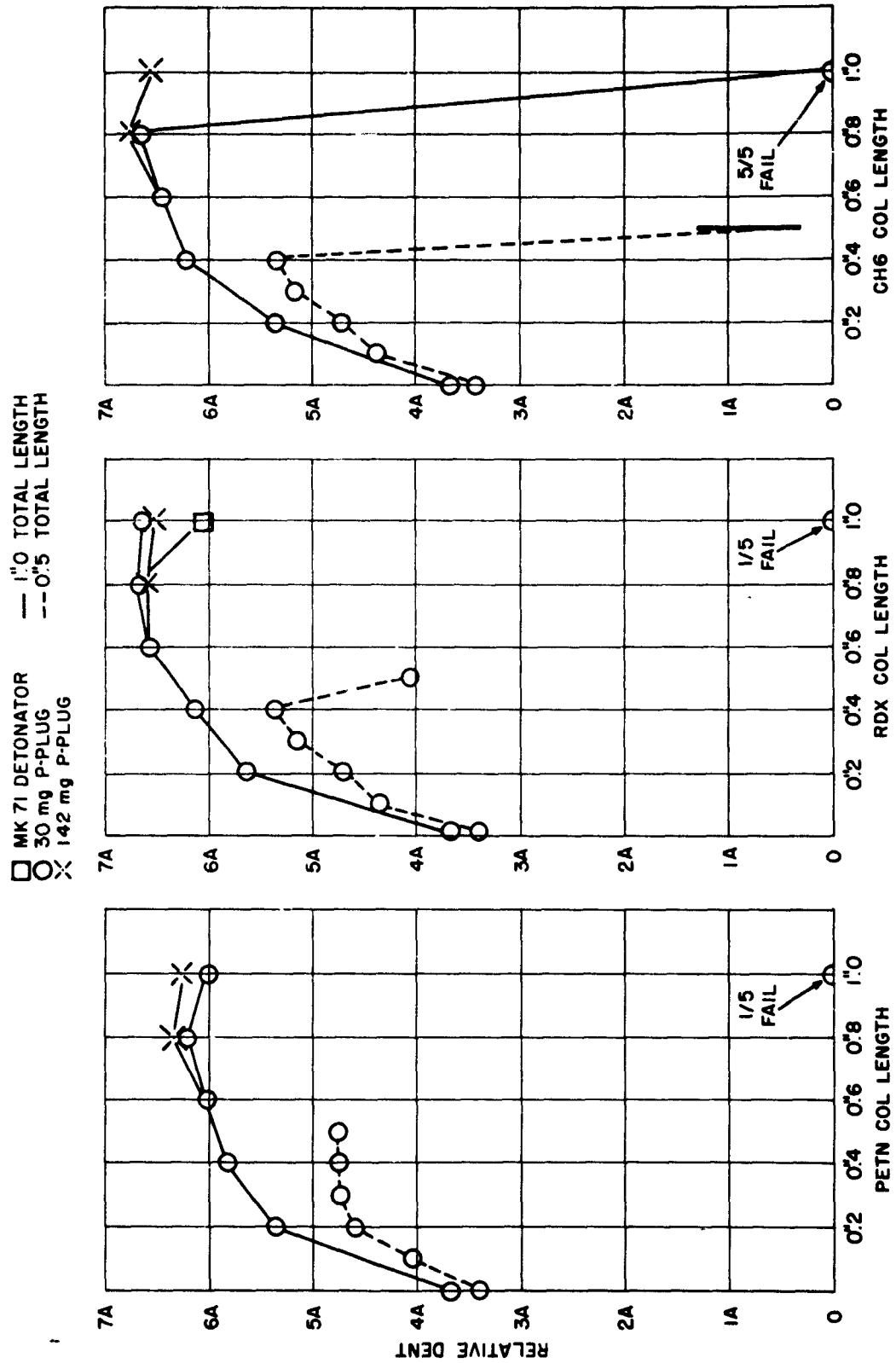
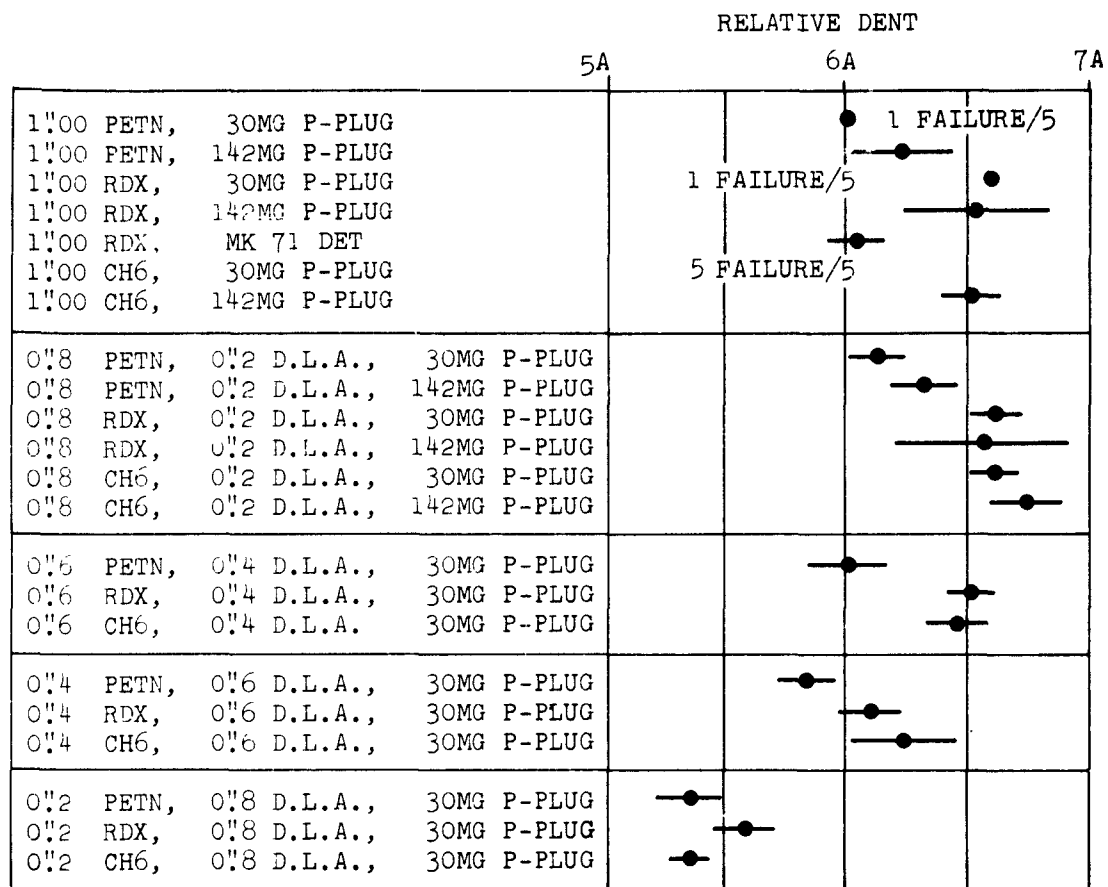


FIG. 4 OUTPUT OF VARIOUS 0.2 DIAMETER, COMPOSITE HIGH EXPLOSIVE-LEAD AZIDE COLUMNS IN 1.0 DIAMETER BRASS BODIES. 5 SHOT DATA

NAVWEPS REPORT 7342



NOTE:

1. DATA PLOTTED AS MEAN PLUS-AND-MINUS ONE STANDARD DEVIATION OF FIVE OBSERVATIONS.
2. D.L.A. = DEXTRINATED LEAD AZIDE.

FIG. 5 ALTERNATE PRESENTATION OF RESULTS SHOWN IN FIG. 4

NAVWEPS Report 7342

the effect is due to fiber orientation or to block hardness.² At a later point in the program, it was found that neither size was thick enough for certain high intensity charges. The decision was made at this time to use the D block 3.0-inch diameter, by 1.5 inches thick.

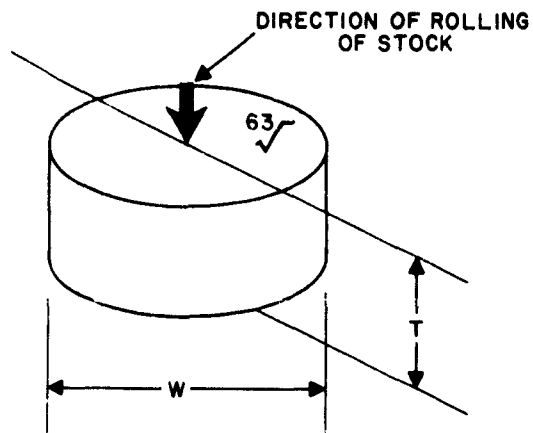
17. An increase of consolidating pressure from 10 KPSI to 12 KPSI causes an increase of dent which is significant at the 95% confidence level, a result which seems to be reasonable. Outputs with the Mk 70 Detonator appear to be consistently more variable and of lesser magnitude than with the Mk 71 Detonator. This trend is definitely contrary to expectations. Previous studies on these detonators showed that the Mk 70 Detonator could be expected to be more powerful and no more variable than the Mk 71.

18. Firing tests and radiographic examination showed that the lot of Mk 70 Detonators did not conform to specifications. Properly loaded Mk 70 Detonators were not available to repeat these tests. It was decided, on the basis of engineering judgment, that the Mk 70 Detonator would be specified for the revised SSGT.

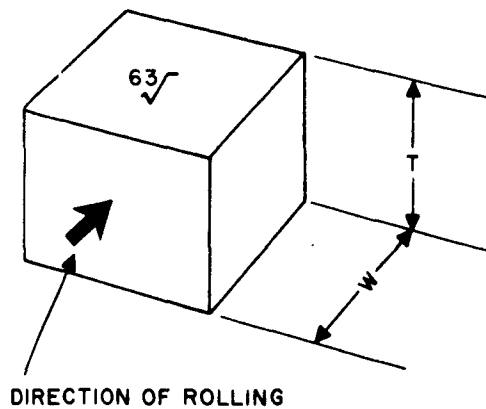
19. The fact that the performance of the 0.8-inch RDX column was so sensitive to the detonator characteristics led to the conclusion that the donor column length should be greater than 0.8 inch. A 1.5-inch long body having a recess for the detonator was chosen in place of the 1.0-inch body. The results of studies with the 1.5-inch bodies are shown in Figures 8 and 9. The bands indicated are ± 1 standard deviation about the mean. From the results, it appeared that the output from even the 1.4-inch long RDX explosive column was still susceptible to the strength of the initiator, but to a lesser degree.

20. A curious relationship is demonstrated in Figure 9: 1.0-inch long RDX columns when loaded into 1.0-inch bodies have less output than when loaded into 1.5-inch bodies. Apparently the extra confinement of the detonators in the latter case increases the detonator efficiency.

2. See, however, NAVORD Report 3983, "Effect of Hardness of the Steel Used Upon the Results of the Steel Dent Test of Detonators", L. D. Hampton, 10 May 1955.



TYPE	W	T	BLOCK SHAPE
A	0.75	0.375	ROUND
B	1.375	0.675	ROUND
C	2.0	1.0	ROUND
D	3.0	1.5	ROUND
E	1.25	0.6	SQUARE
F	1.5	1.0	SQUARE
G	2.0	0.72	SQUARE
H	2.0	0.95	SQUARE



ALL BLOCKS HARDENED TO ROCKWELL
B 70-95.

DENT TEST SURFACE OF ROUND BLOCKS
PERPENDICULAR TO DIRECTION OF
ROLLING.

DENT TEST FACE OF SQUARE BLOCKS
PARALLEL TO DIRECTION OF ROLLING.

DIMENSIONS IN INCHES.

FIG. 6 CONFIGURATION OF STEEL DENT BLOCKS

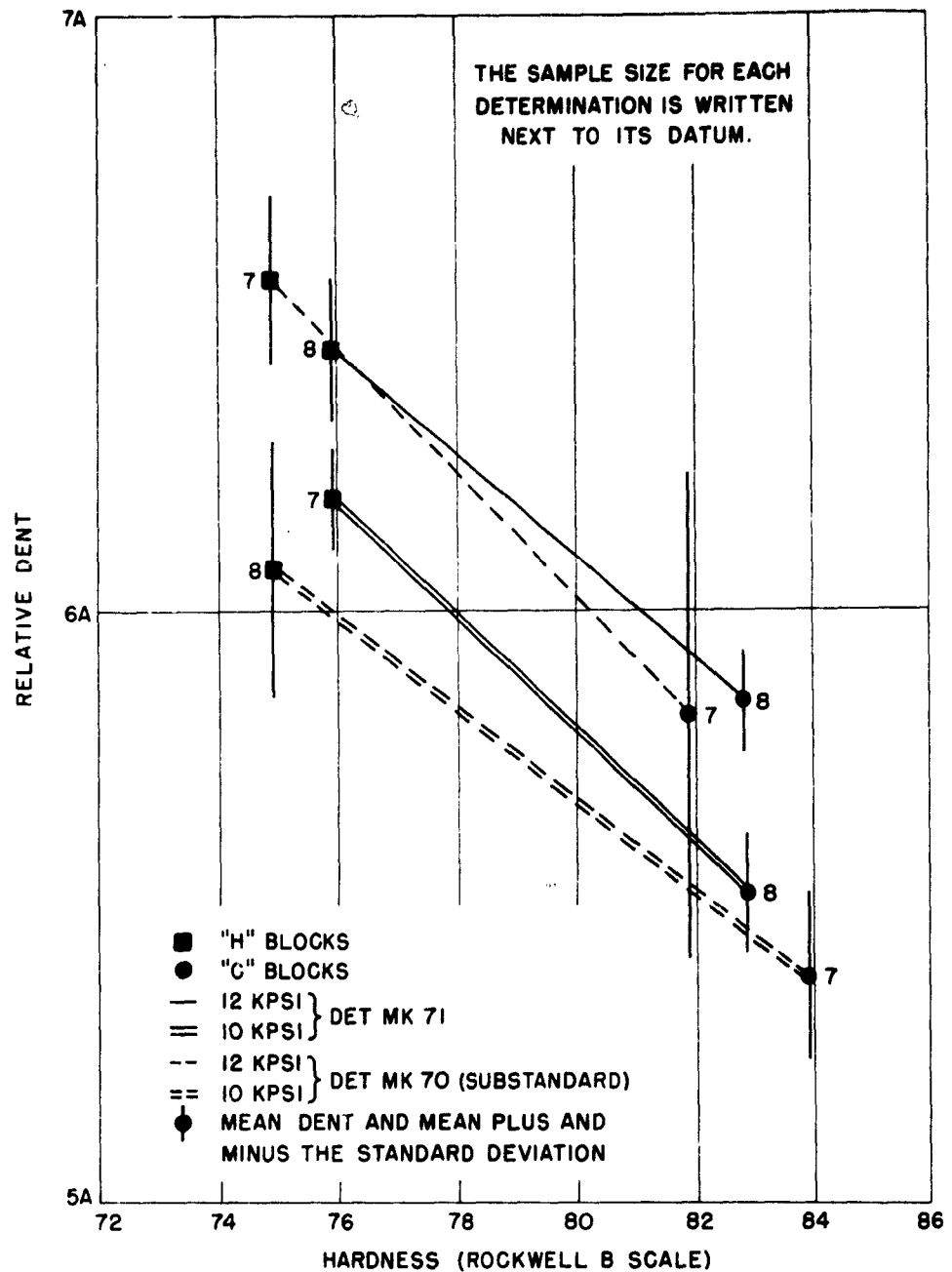


FIG. 7 THE EFFECT OF BLOCK TYPE, CONSOLIDATING PRESSURE, AND INITIATOR ON THE OUTPUT OF AN EXPLOSIVE COLUMN.

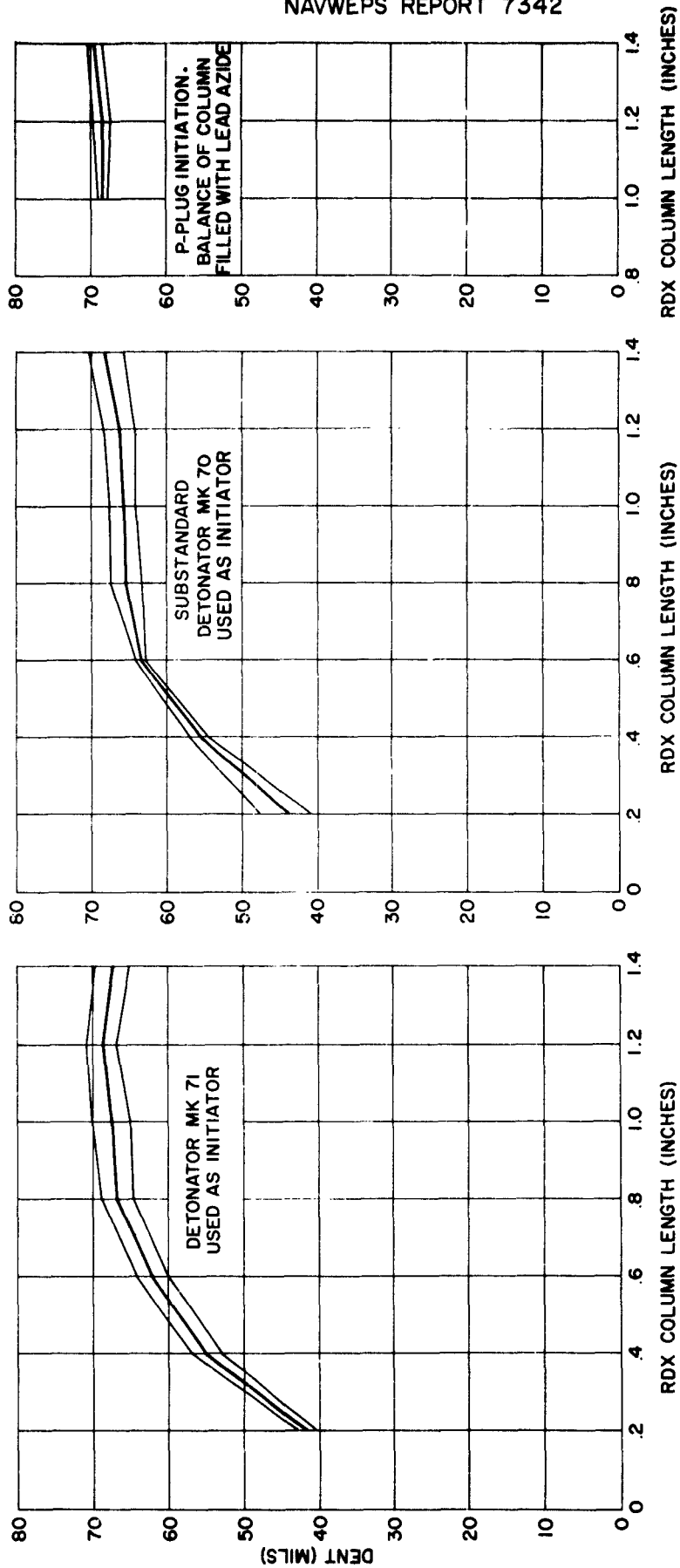


FIG. 8 OUTPUT OF VARIOUS LENGTH RDX COLUMNS
LOADED AT 10 KPSI IN 1"5 BODY, 1"0 DIA

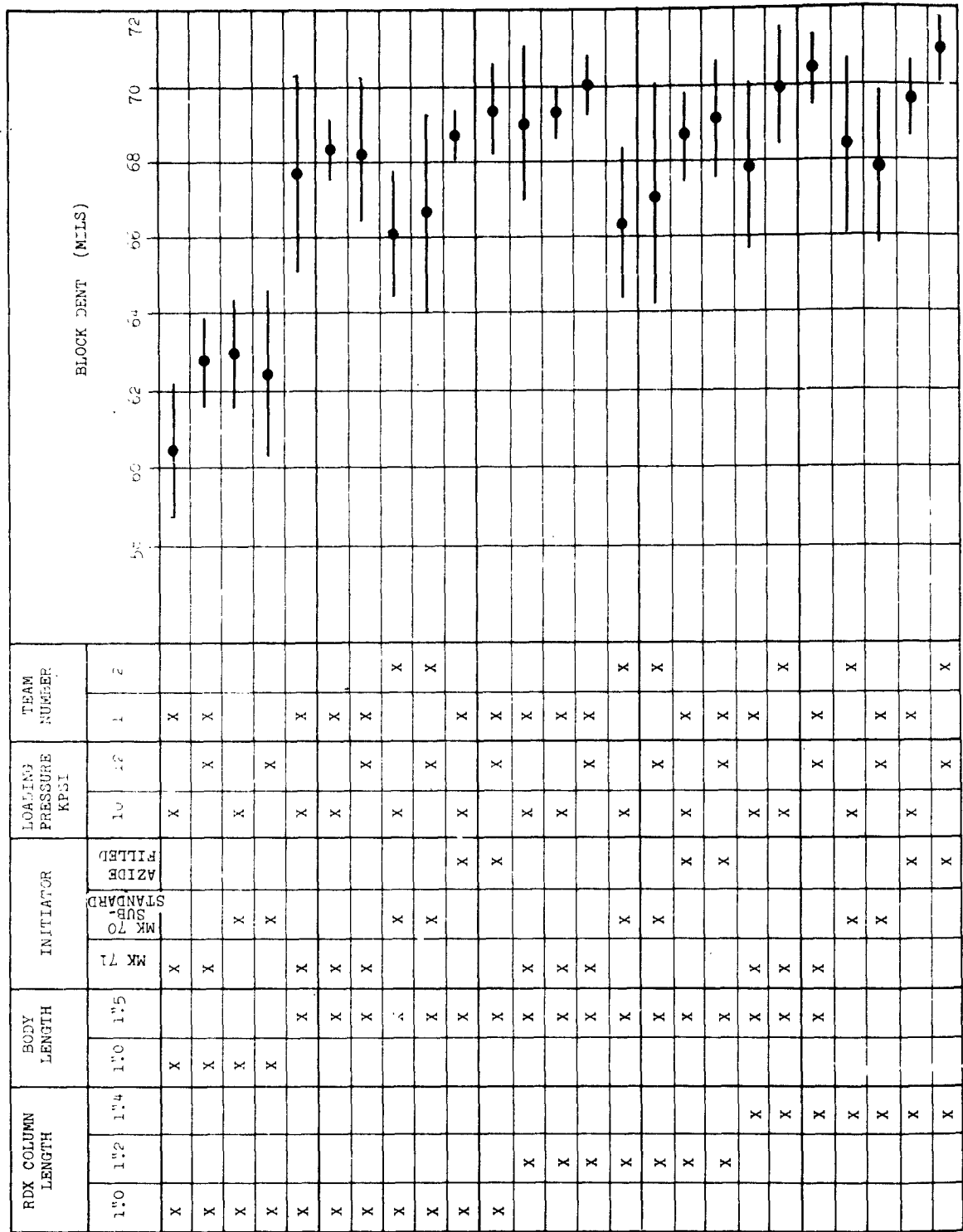


FIG. 9 A STUDY OF 1:0, 1:2 AND 1:4 LONG RDX COLUMNS

21. Check runs were made with two teams of ordnancemen doing loading and firing. The data are shown in Figure 9. The data do not seem to show any significant difference although some samples loaded by team 1 have a little less output and are a little more variable than is the case for team 2. At this point in the program it was decided to measure and record the column lengths of all donor charges. It was suspected that the fact that column lengths were to be written down would tend to decrease operator errors.

22. Variation in column height is not necessarily indicative of loading error. A 2-mil variation in the inside diameter of the body will cause a variation in volume of 2%. Actual charge weights can be determined to better than 0.2% by weighing the body before and after loading. Column heights can be measured to better than 0.1%. It seemed evident that donor quality control procedures should include materials control on the purity and particle size of the RDX; measurement of charge weight, diameter, and length; and measurement of the dent output of a properly chosen sample.

EFFECT OF GAP ON DONOR OUTPUT

23. After deciding that the 1.4-inch long column of RDX with a Mk 70 Detonator would be used as the donor, output studies of this donor, and of the old low intensity donor as a function of air gap and of plastic barrier thickness were undertaken.

24. Figures 10 and 11 are plots of the effect of air and lucite on the output of the 0.2-inch diameter, low intensity, lead azide, donor. The data were plotted on semi-logarithmic paper on the assumption that the donor output (assumed linearly related to the steel dent produced by the donor) falls off exponentially with air gap. This method of plotting tends to put an undue emphasis on the small dents (3 mils and less). To illustrate, an error band of ± 0.5 mils was drawn about the eye-fitted straight line in Figure 10. Points outside of the error band are felt to represent true variability arising from errors in gap measurement, from the inherent variability in explosive charge, and perhaps from variability in steel block response. Comparison of the air gap and lucite barrier results showed that the plastic barrier is a more effective attenuator and that the straight line fit may not be quite valid. Above 100-mils gap the attenuation is somewhat greater than would be expected. The overall system variability may have been somewhat

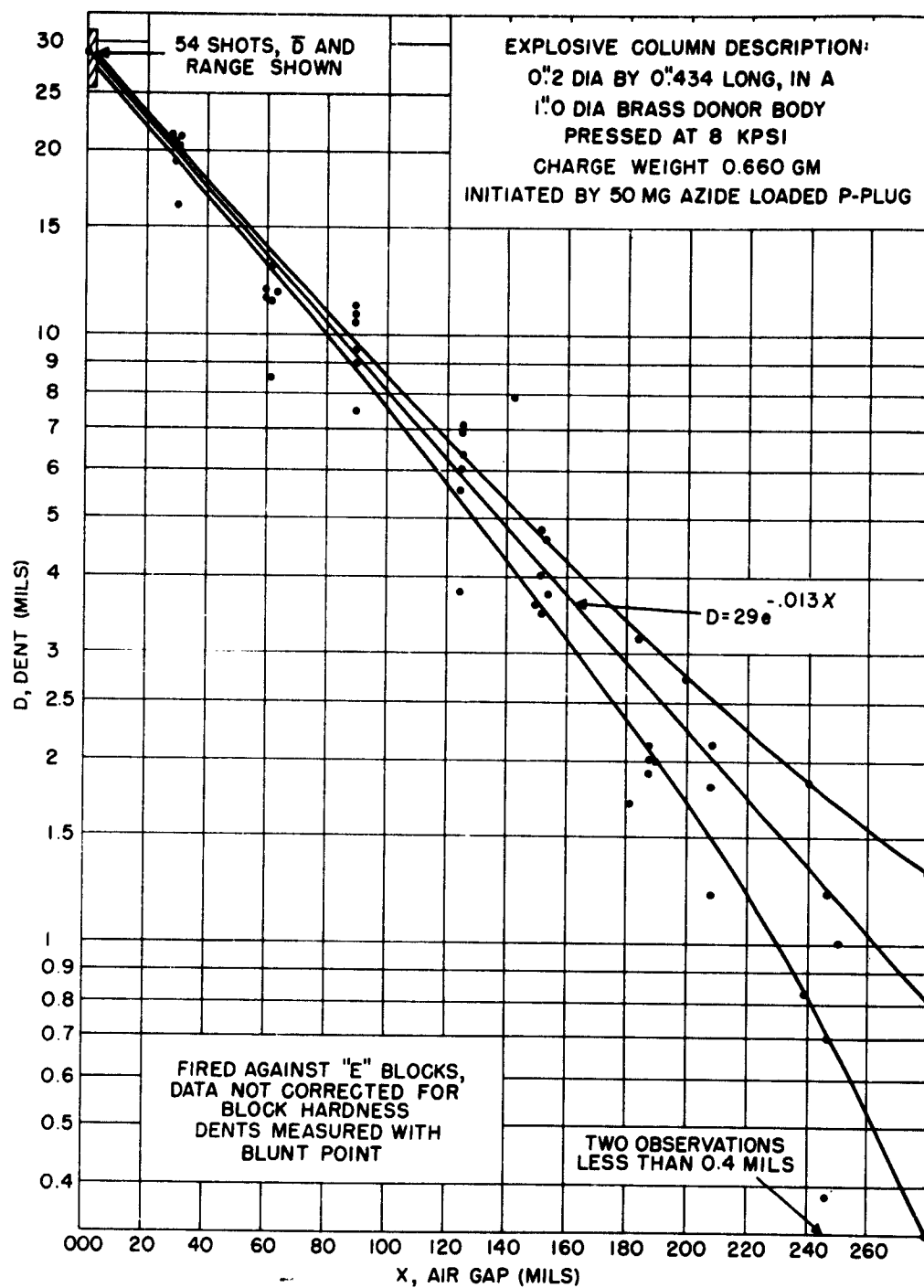


FIG. 10 EFFECT OF GAP (AIR) ON OUTPUT
 OF 0.2 DIA LEAD AZIDE COLUMN

NAVWEPS REPORT 7342

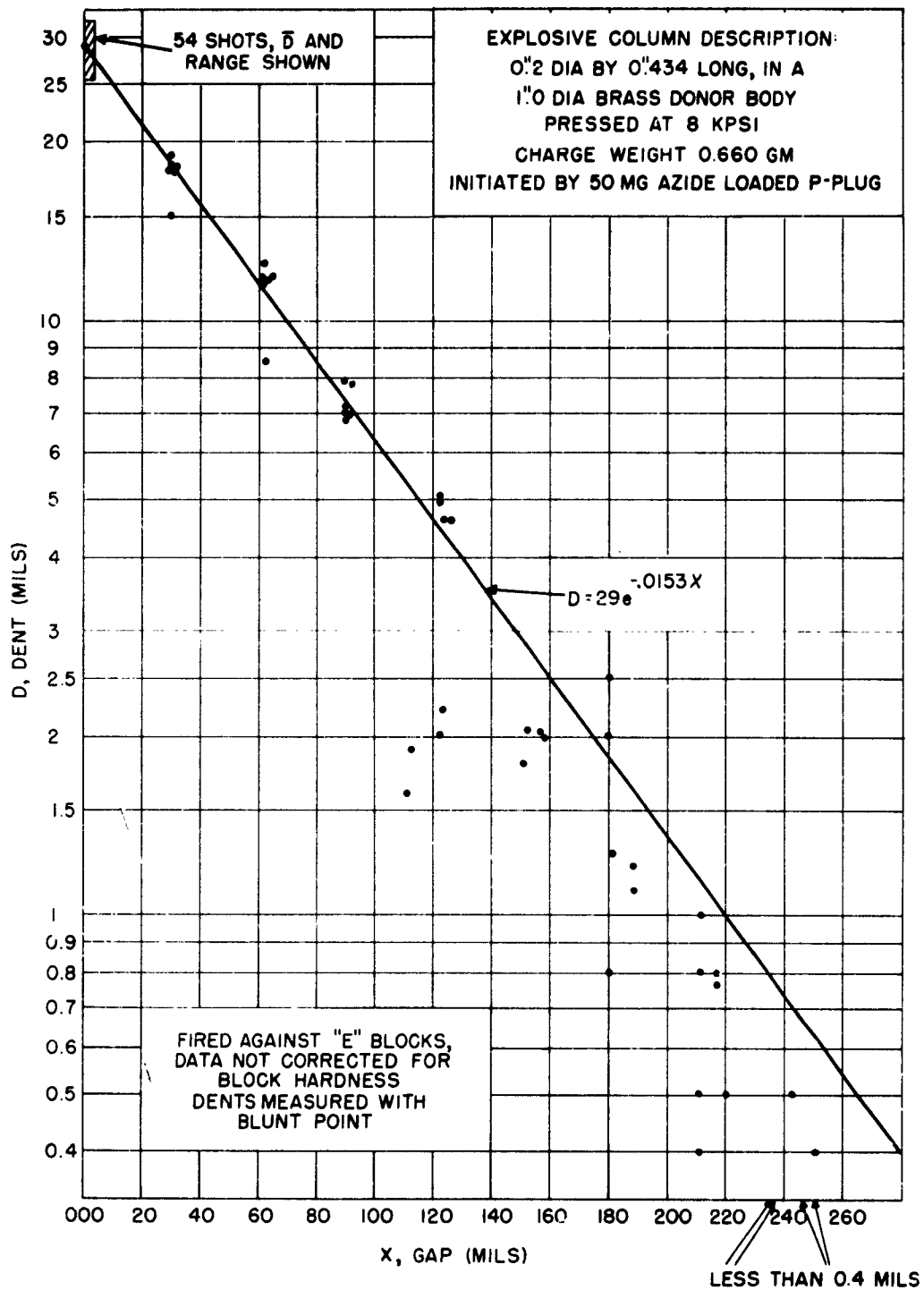


FIG. II EFFECT OF LUCITE BARRIER ON OUTPUT
 OF 0.2 DIA LEAD AZIDE COLUMN

NAVWEPS Report 7342

reduced with the plastic barrier -- presumably because of an improvement in ability to measure the gap spacing. Similar studies with 0.15-inch diameter azide donor did not show a similar differentiation between air and plastic in the gap (see Figure 12), because of reduced explosive vigor and limited sample size. However, the exponential model still seems to be reasonable.

25. Figures 13 and 14 show the results of tests with the high intensity donor. The lucite barrier gives a sharper attenuation than does the air gap, and also reduces dent variability. All five eye-fitted straight line functions are plotted together in Figure 15 to facilitate comparisons. The values of the coefficients of the fitting curves are given in Table I. The results appear self consistent. However, some caution should be exercised against broad generalizations.

TABLE I. Coefficients of Gap (or Barrier)-Output Exponential Equations for Various Systems.

$$D = B \exp(-mX)$$

Column Diameter (inches)	0.2	0.2	0.2	0.2	0.15
Explosive	RDX	RDX	DLA	DLA	DLA
Type of Gap	air	plastic	air	plastic	air or plastic
B, Dent(mils) at X = 0.0	68.0	68.0	29.0	29.0	17.3
X, Gap(mils) at D = 1 mil	575	470	260	220	148
m	0.0073	0.0090	0.0130	0.0153	0.0193

DLA = Dextrinated Lead Azide

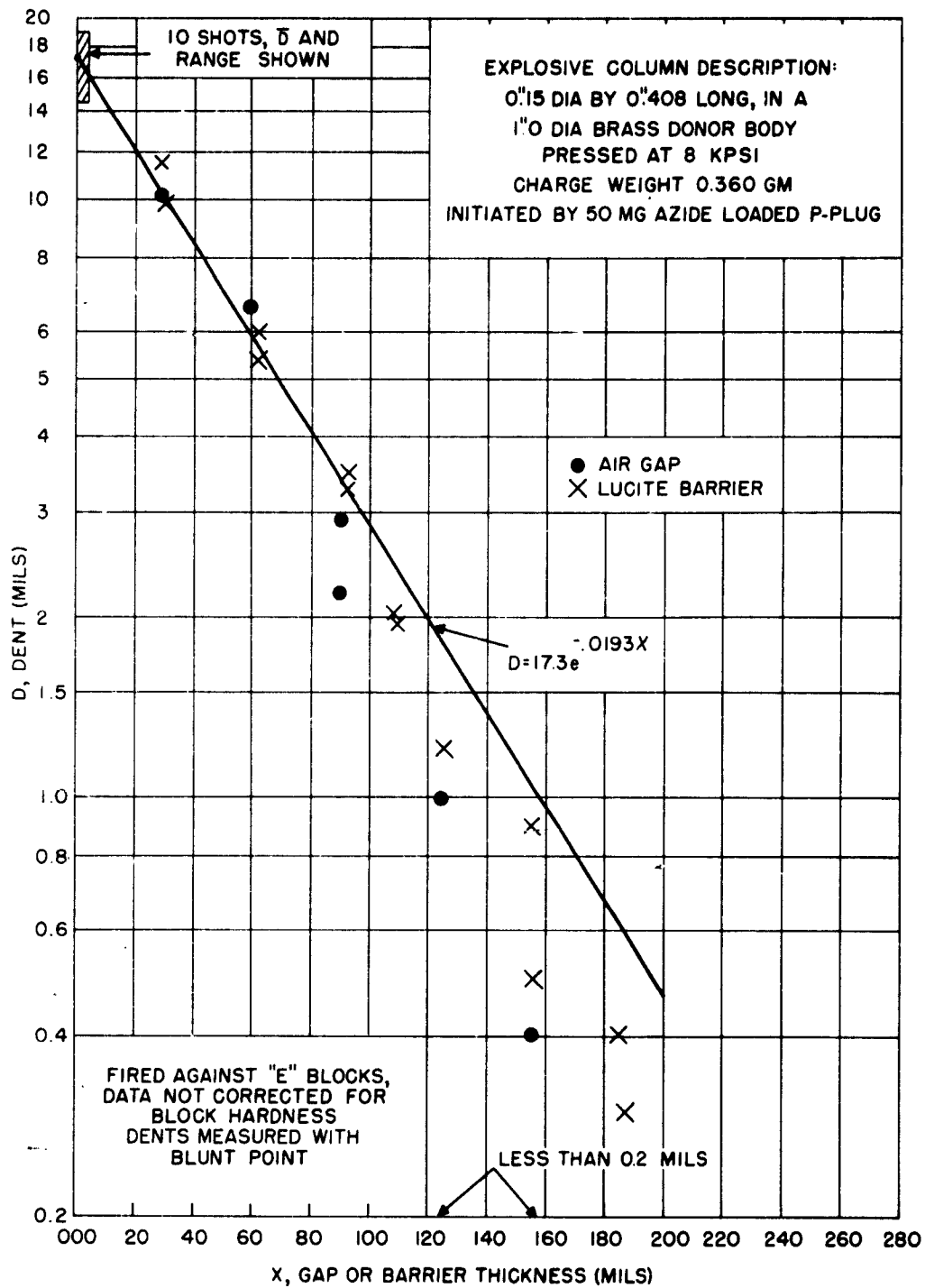


FIG. 12 EFFECT OF GAP (AIR) AND OF LUCITE BARRIER
 ON OUTPUT OF 0.15 LEAD AZIDE COLUMN

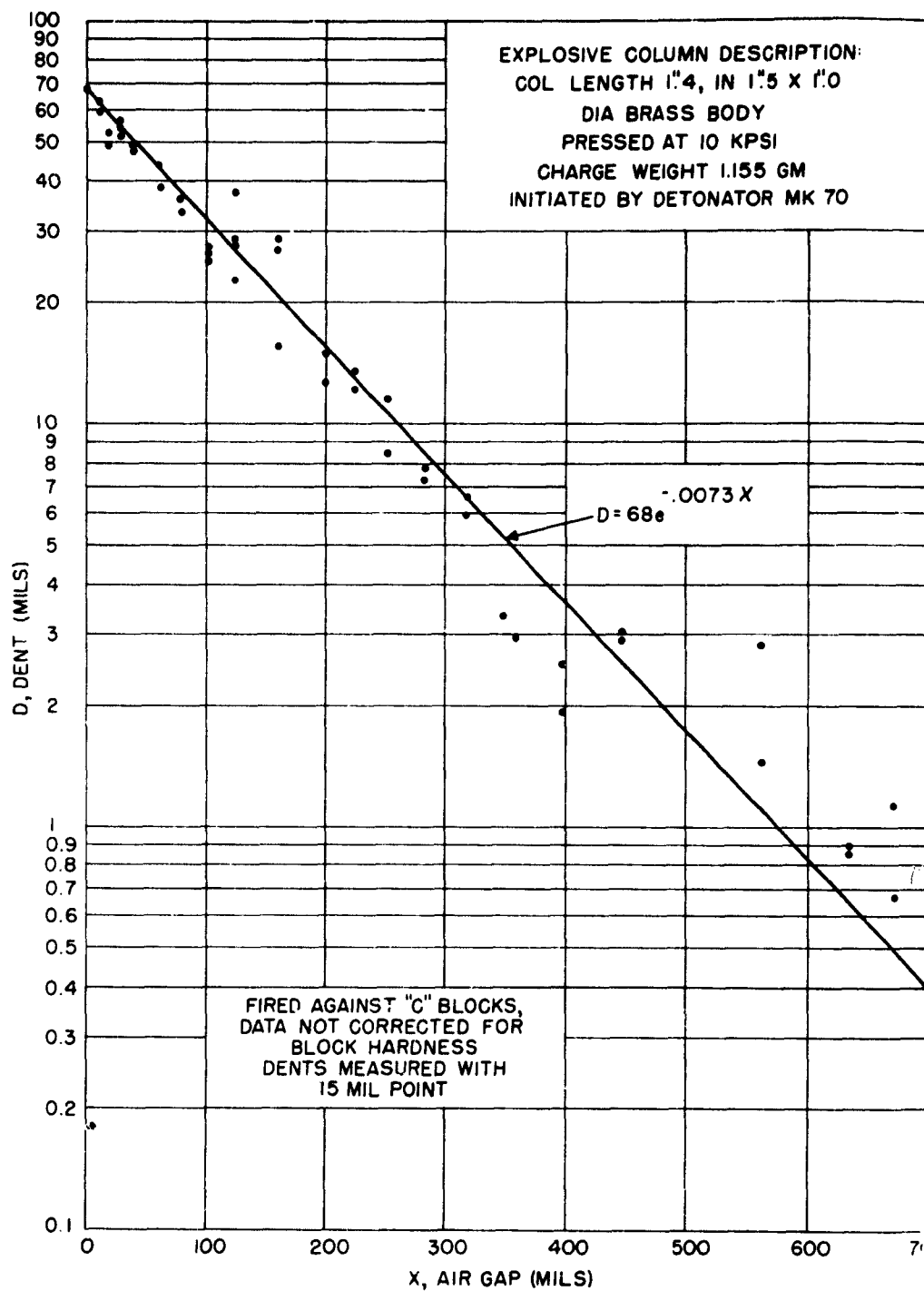


FIG. 13 EFFECT OF GAP (AIR) ON OUTPUT
OF 0.2 DIA RDX COLUMN

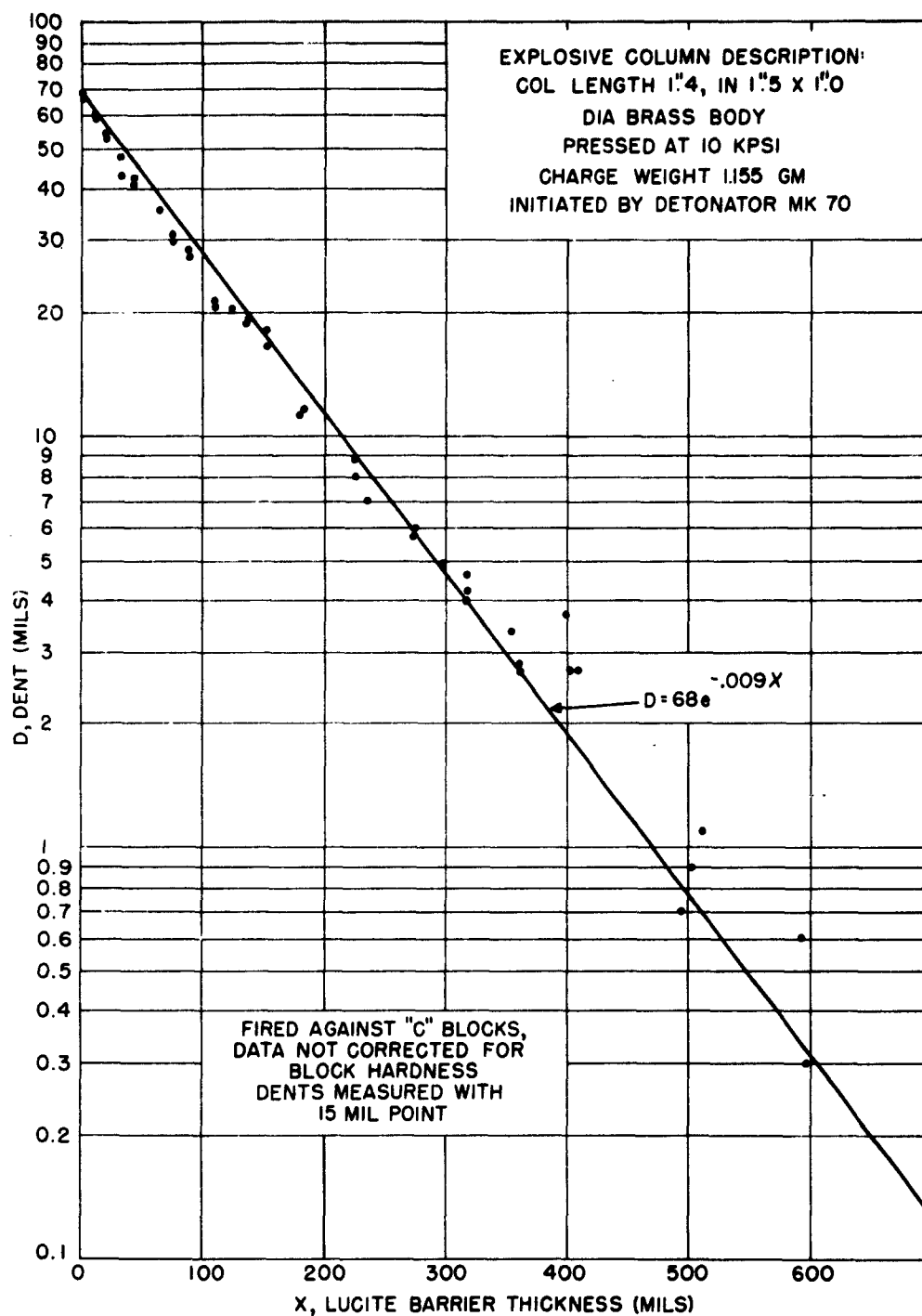


FIG. 14 EFFECT OF LUCITE BARRIER ON DENT OUTPUT
OF 0.2 DIAMETER, RDX COLUMN

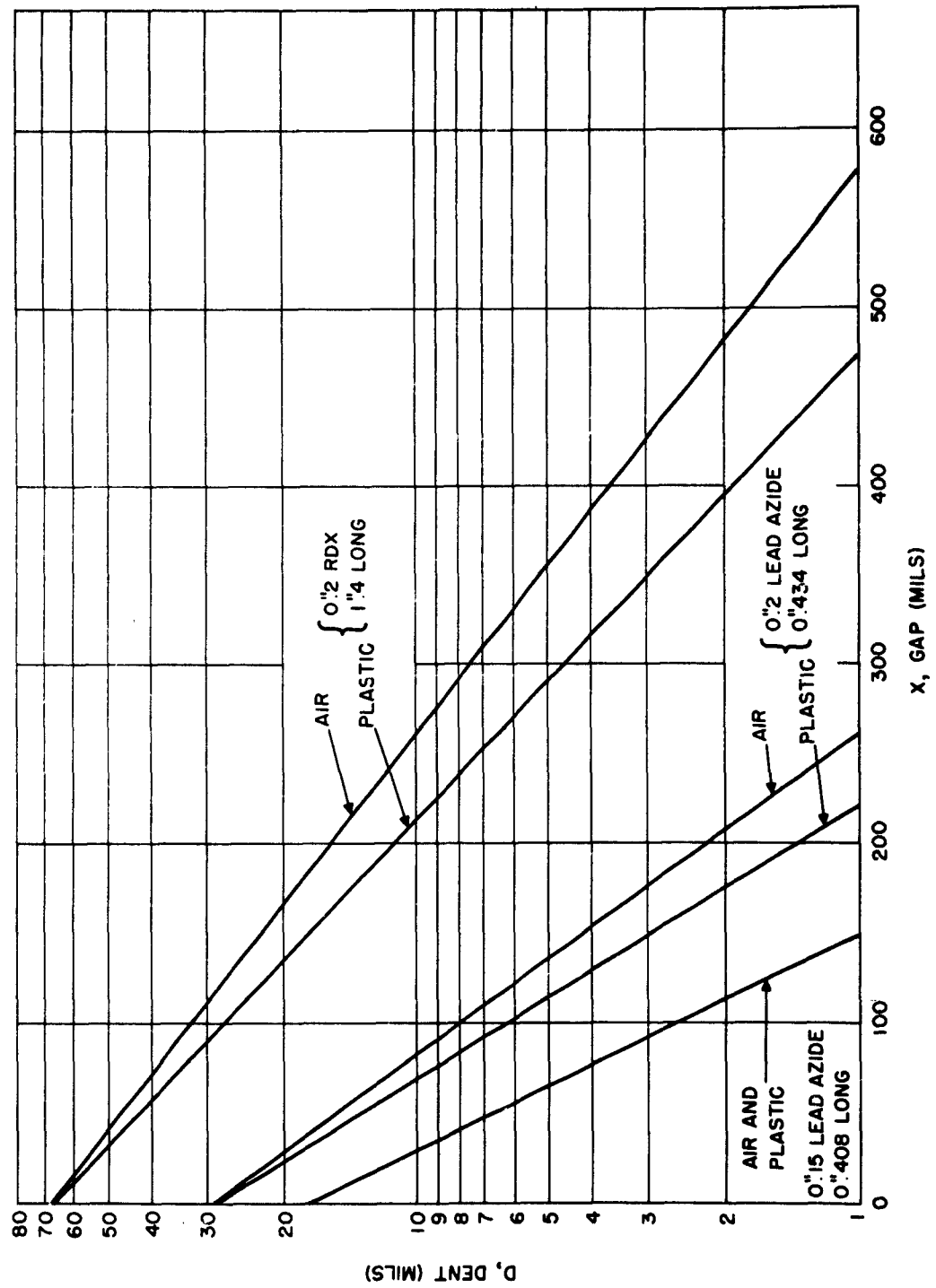


FIG. 15 COMPARISON OF ATTENUATION BY AIR AND BY LUCITE

26. The results plotted are the depth of dent versus gap. The volume of dent would be expected to give different results since the shape of the dent also changed with the gap. With spacing in the order of 0.050 inch or less the dent was nearly flat bottomed and roughly of the same diameter as the donor charge -- 0.2 inch, as in Figure 16(a). At greater spacings

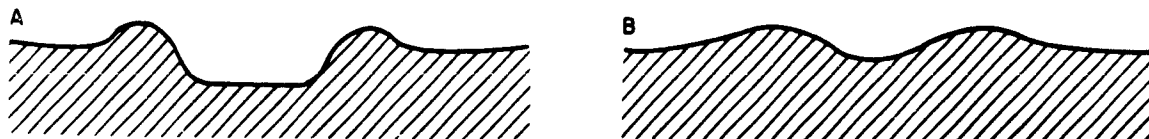


FIG. 16 TYPES OF DENT, QUALITATIVE REPRESENTATION

the dent became roughly spherical in bottom profile. The transition from flat-bottomed to round-bottomed dent occurred at about the same depth of dent for a given donor whether the gap was air or plastic. Attempts were made to evaluate the volume of dent. These were abandoned when it was felt that the effort to obtain the measurements was not in keeping with the utility of the information to the present project. Various interesting shrapnel and scorch marks were noted. The appearance of the markings seemed to vary with gap spacing. It is possible that a carefully controlled extension of this experiment could give some revealing insight into the dynamics of shocks produced by small explosive charges.

27. As can be seen in Figure 16, a ring of metal was upset around the dent by the explosion. The depth of dent was measured as the distance below the undisturbed metal surface.

28. The effect of the plastic barrier material and configuration was studied. Experiments, with 0.010-inch thick cellulose acetate sheets stacked up to a given dimension, with multilayer lucite, and with one piece lucite barriers, showed no differentiation between the attenuation of the three types of barriers. Because it seemed desirable to have as few interfaces as possible in the barrier system, arrangements were made to obtain molded lucite discs 1.0-inch diameter, with thicknesses chosen on a logarithmic scale. While waiting for these molded pieces, lucite barriers machined from rod stock (flat face

perpendicular to extended surface), and from sheet stock (flat face identical with or parallel to extended surface) were used. No detectable differences were observed between the three lucite barrier types.

THE GAP DECIBANG

29. The logarithmic gap transform was found necessary to normalize the response distribution function in the SSGT. In any single test the gap for a low response (1 out of 20) is so close to the gap for a high response (19 out of 20) that it would be difficult to demonstrate a difference between linearly spaced and logarithmically spaced intensity levels. However, tests involving very insensitive and very sensitive explosives show that the size of the standard deviations tend to be proportional to the mean gap, \bar{X} . If the response of a system is normally distributed the standard deviation should be independent of the mean³. If insensitive and sensitive explosives tested on the SSGT differ only because of sensitivity and not because of variations of mechanism of response, then the variation of s with \bar{X} is sufficient evidence that response is not normally distributed with linear variation in gap.

30. The simplest normalizing function to use is the one based on the assumption that the initiating intensity is proportional to the logarithm of the reciprocal gap. It can easily be shown that equal steps in this transformed system are spaced at equal percentage intervals or, in other words, at geometric rather than arithmetic intervals. Since there is no assumption that the absolute energy of any particular donor-barrier configuration is known, it becomes necessary to pick some arbitrary point as a reference level to which all other donor-barrier configurations can be related. To underline this concept, and as a matter of convenience, it was decided to define a unit of initiation intensity called the Gap Decibang, DBg, which is analogous to the decibel. The transformation function then becomes:

$$X = A + 10 B \log \frac{GR}{GT}$$

where

X = initiation intensity in DBg
A, B = arbitrary constants
GR = reference gap
GT = observed gap.

3. See A. Hald, "Statistical Theory with Engineering Applications", (John Wiley and Sons, 1952 Edition), pp. 175-176. Also a fundamental assumption in the commonly used analysis of variance is that the standard deviations of all populations is the same although they may have different means.

The function can assume a number of equivalent forms, depending upon the size of the reference gap and the units in which the gaps are expressed. In the original and the revised SSGT, the reference gap was chosen as 1.0 inch. If GT is expressed in inches, the transformation becomes

$$X = -10 \log GT,$$

or if in mils

$$X = 30 - 10 \log GT.$$

31. It should be noted that the greater the DBg value, the greater the initiation intensity because the gap (and therefore the attenuation of the donor) is smaller. Table II is a list of the nominal dimensions and manufacturing tolerances established for the molded lucite attenuators. The tolerances were found compatible with manufacturing processes. The space between steps is somewhat less than the tolerance band for each step, indicating that the step size resolution is about at its practical limit. The steps were spaced at regular 0.125 DBg intervals. The tolerances were set not to exceed 0.05 DBg on either side of the nominal value. This means that each step is 1.0292 times greater than that immediately preceding and that the allowable variation above or below is no more than 1.15% of the step size.

32. It was now appropriate to replot the data of Figures 13 and 14 as linear dent versus Gap Decibangs, see Figures 17 and 18. It was evident that the data could not be fitted by a straight line since at zero gap the DBg value is infinite. However, if a sensitivity test on an explosive were to require zero gap as one of the test levels, the assumption of a normal distribution function is invalidated as a matter of course. For initiation intensities between 17 DBg (gap 0.020 inch) and 5 DBg (gap 0.316 inch) the assumption of a log normal relation seemed good. The attenuated donor output dent is not necessarily linearly related to the initiation intensity to which the various acceptor explosives respond. The basic assumption was that the dent produced by various attenuated donors was a continuous monotonic function of the initiation intensity characteristic of these donors.

DONOR LOADING INFORMATION

33. It is intended that a complete procedure (probably a set of specifications) will be written which will describe explosive charge preparation methods, inert material quality controls and SSGT test firing procedures. Until such material becomes available, the following information can be employed.

TABLE II

**Nominal Dimensions and Manufacturing
Tolerances of Lucite Attenuators**

<u>Pc. No.</u>	<u>Decibang Value</u>	<u>Nominal Thickness (mils)</u>	<u>Manufacturing Tolerances (mils)</u>		<u>±0.05 DBg from Nominal Thickness (mils)</u>	
			<u>Min</u>	<u>Max</u>	<u>Min</u>	<u>Max</u>
1	8-1/2	141.3	139.6	142.9	139.6	142.9
2	8-3/8	145.4	143.7	147.1	143.7	147.1
3	8-1/4	149.6	147.9	151.4	147.9	151.4
4	8-1/8	154.0	152.2	155.8	152.2	155.8
5	8	158.5	156.7	160.3	156.7	160.3
6	7-7/8	163.1	161.3	165.0	161.3	165.0
7	7-3/4	167.9	166.0	169.8	166.0	169.8
8	7-5/8	172.8	170.8	174.8	170.8	174.8
9	7-1/2	177.8	175.8	179.8	175.8	179.8
10	7-3/8	183.0	181.0	185.0	181.0	185.0
11	7-1/4	188.4	186.4	190.4	186.4	190.4
12	7-1/8	193.9	191.9	195.9	191.9	195.9
13	7	199.5	197.5	201.5	197.5	201.5
14	6-7/8	205.4	203.4	207.4	203.0	207.7
15	6-3/4	211.4	209.4	213.4	208.9	213.8
16	6-5/8	217.5	215.5	219.5	215.0	220.0
17	6-1/2	223.9	221.9	225.9	221.3	226.5
18	6-3/8	230.4	228.4	232.4	227.8	233.1
19	6-1/4	237.1	235.1	239.1	234.4	239.9
20	6-1/8	244.1	242.1	246.1	241.3	246.9
21	6	251.2	249.2	253.2	248.3	254.1
22	5-7/8	258.5	256.5	260.5	255.6	261.5
23	5-3/4	266.1	264.1	268.1	263.0	269.2
24	5-5/8	273.8	271.8	275.8	270.7	277.0
25	5-1/2	281.8	279.8	283.8	278.6	285.1
26	5-3/8	290.1	288.1	292.1	286.7	293.4
27	5-1/4	298.5	296.5	300.5	295.1	302.0
28	5-1/8	307.3	305.3	309.3	303.7	310.8

TABLE II (Cont'd.)

<u>Pc. No.</u>	<u>Decibang Value</u>	<u>Nominal Thickness (mils)</u>	<u>Manufacturing Tolerances (mils)</u>		<u>±0.05 DBg from Nominal Thickness (mils)</u>	
			<u>Min</u>	<u>Max</u>	<u>Min</u>	<u>Max</u>
29	5	316.2	314.2	318.2	312.6	319.9
30	4-7/8	325.5	323.5	327.5	321.7	329.2
31	4-3/4	335.0	333.0	337.0	331.1	338.8
32	4-5/8	344.7	342.7	346.7	340.8	348.7
33	4-1/2	354.8			350.8	358.9
34	4-3/8	365.2			361.0	369.4
35	4-1/4	375.8			371.5	380.2
36	4-1/8	386.8			382.4	391.3
37	4	398.1			393.6	402.7
38	3-7/8	409.7			405.0	414.5
39	3-3/4	421.7			416.9	426.6
40	3-5/8	434.0			429.0	439.0
41	3-1/2	446.7			441.6	451.9
42	3-3/8	459.7			454.5	465.1
43	3-1/4	473.2			467.7	478.6
44	3-1/8	487.0			481.4	492.6
45	3	501.2			495.5	507.0

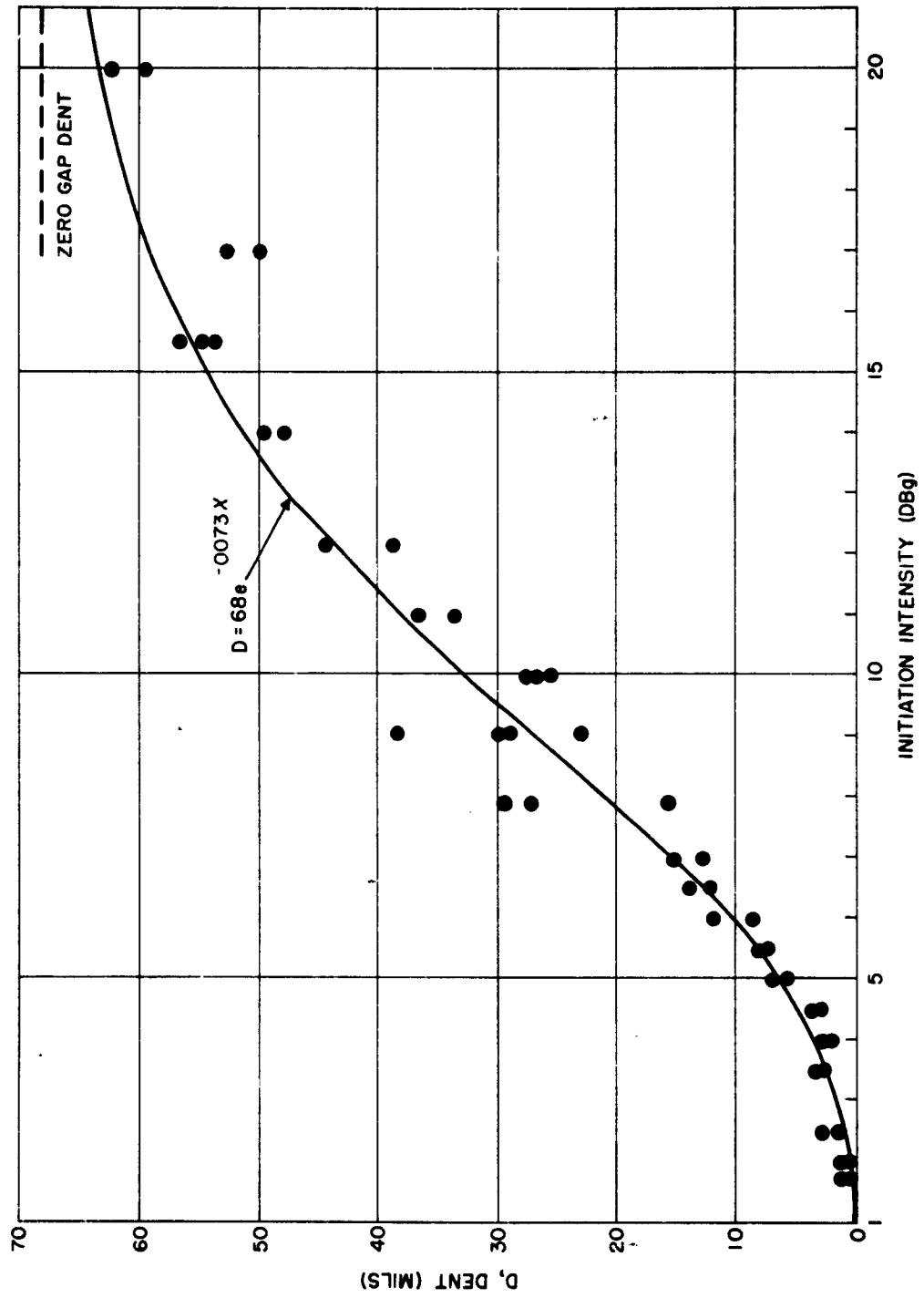


FIG. 17 OUTPUT ATTENUATION OF REVISED SSGT DONOR BY AIR

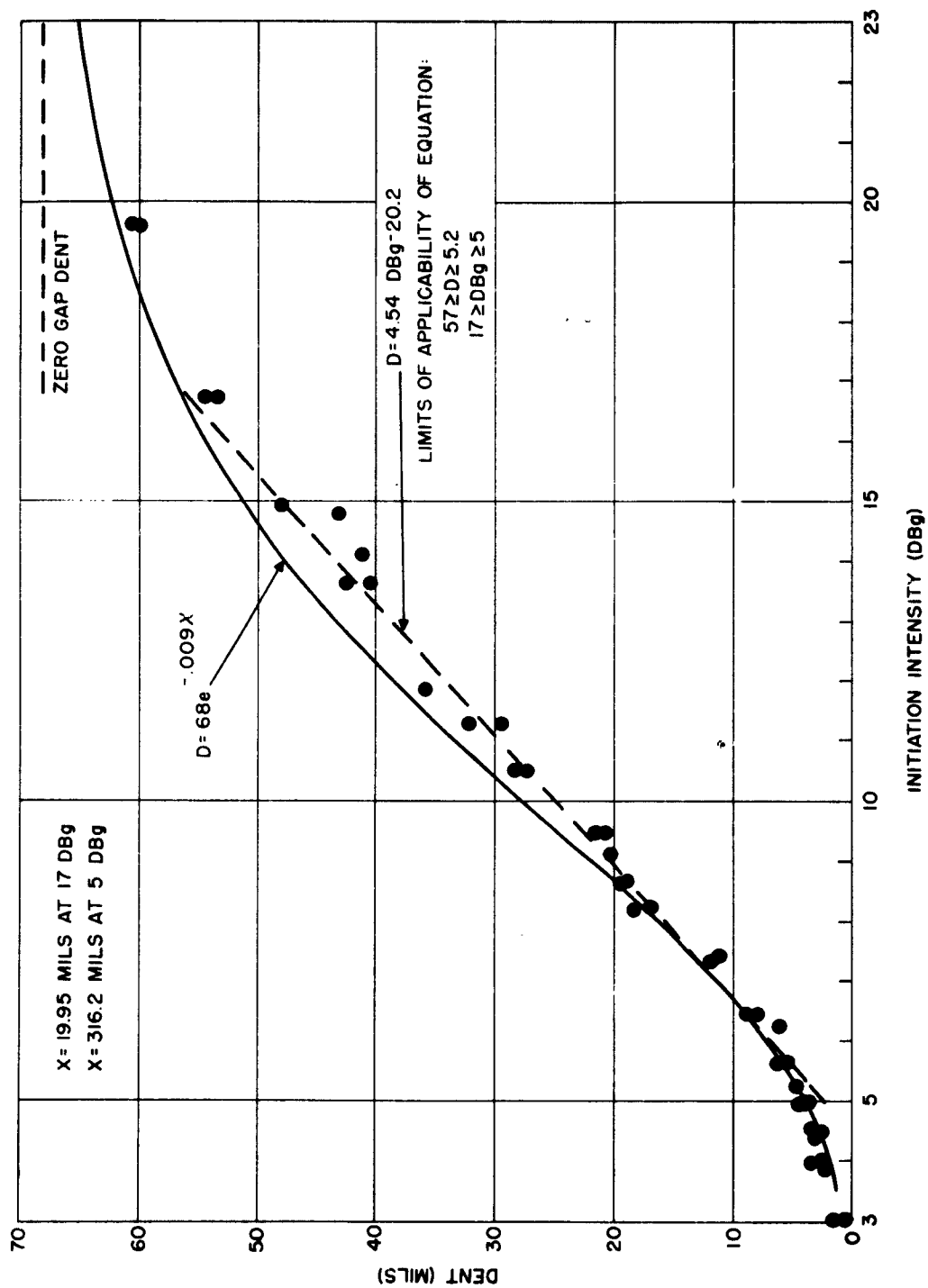


FIG 18 OUTPUT ATTENUATION OF REVISED SSGT DONOR BY LUCITE

34. Over 230 donors were loaded and fired against steel dent blocks, some in the original design program, the rest as part of the random sampling from the donor manufacturing runs. The explosive charge weight and volume were measured for each donor. The weight was determined from the donor body weight before and after loading with an accuracy of about ± 4 milligrams (about $\pm 0.43\%$). The charge volume was determined from measurements of the column length and charge diameter; column length measurement accuracy is ± 0.002 , or to $\pm 0.14\%$, and charge diameter measurement accuracy is ± 0.0002 or $\pm 0.1\%$. From these data, a charge density was computed for each donor. Correlation studies were then carried out on various possible pairs of the following factors: output dent, charge density, charge weight, charge length, and charge diameter. The factors which showed significant interactions at 95% confidence were then censored by removing extreme data points. The censoring process consisted of determining an average value enclosed by symmetrical limits such that about 90% of the observed data points would fall within these limits. The censored data were then re-evaluated by the correlation program. Except for column length versus density, it was no longer possible to demonstrate any interactions between the various factors. This was assumed to mean that variations within the censor limits would not give rise to detectable variations in the donor output. These limits were therefore used as the basis for setting the production inspection limits given in Table III. It should be noted that these limits are independent controls in that it would be possible for a piece to pass any three of the limits and still fall outside of the fourth limit.

TABLE III. Donor Acceptance Limits

<u>Factor</u>	<u>Nominal</u>	<u>Tolerance</u>	<u>Min.</u>	<u>Max.</u>
Density (g/cc)	1.556	$\pm 2\%$	1.525	1.587
Length (inch)	1.430	$\pm 2\%$	1.400	1.460
Charge Weight (gms)	1.150	$\pm 2\%$	1.127	1.173
Hole Diameter (inch)	--	--	0.2000	0.2012

35. The control on hole diameter was not as direct nor its need as obvious as for the other three factors. For maximum production rate it was desirable to press at one pressure and to use one ram diameter. Under these conditions the densities obtained were amazingly sensitive to the amount of clearance between the ram and the donor hole. Figure 19, a plot of over 1900 observations, shows a curious relationship in that a minimum charge density at 10 KPSI is noted for a clearance of about 1.1 mils. By centering the variation in clearance (and therefore the allowable hole variation) around this value it was expected that a minimum density variation would be encountered for a hole tolerance of ± 0.75 mils.

36. The salient features in the design of the donor body are given in Figure 20. Particular care was needed in maintaining the "trueness" of the hole -- sharp corners, perpendicularity, runout, and finish. Tolerances and controls were set as loosely as possible commensurate with what were judged to be the engineering needs. The piece was suitable for turret-lathe or screw-machine manufacture and was procured on the open market at a price of about \$250 a thousand for a lot of fifteen thousand. (Price reflects cost levels in the spring of 1960). The materials price was a major portion of this cost.

37. The donor, Figure 21, is loaded in seven equal increments. An increment height about equal to the charge diameter assures an optimum between uniformity of charge density and loading man hours. The RDX loaded into the donor is a service grade of explosive. The only bulk preparation was drying of the explosives at 50°C for 4 hours under a vacuum of 28 mm Hg or less. It should be remembered that the RDX was only about 92.5% $\pm 2.5\%$ pure - the balance was HMX. Further studies of the explosive composition and physical chemistry may at some time in the future become of paramount importance to the maintenance of donor quality. The fact that these parameters may not be sufficiently well controlled by present specifications can for the moment be set aside on the assumption that they will probably not give rise to first order variations. However, this decision and assumption must not be forgotten.

38. "Spring-back" (the expansion in explosive column length after removal of the pressing load) has given rise to some trouble during donor manufacture. It was found that independent of dwell time the output end of the donor explosive charge would expand from 5 to 10 mils beyond the bottom of the donor body. A simple brass shaving tool was devised to clean the explosive off flush with the end of the donor body.

39. The determination of charge weight involved precise measurements of the net and gross body weights. The bodies weighed about 150 to 160 grams and the difference in the two

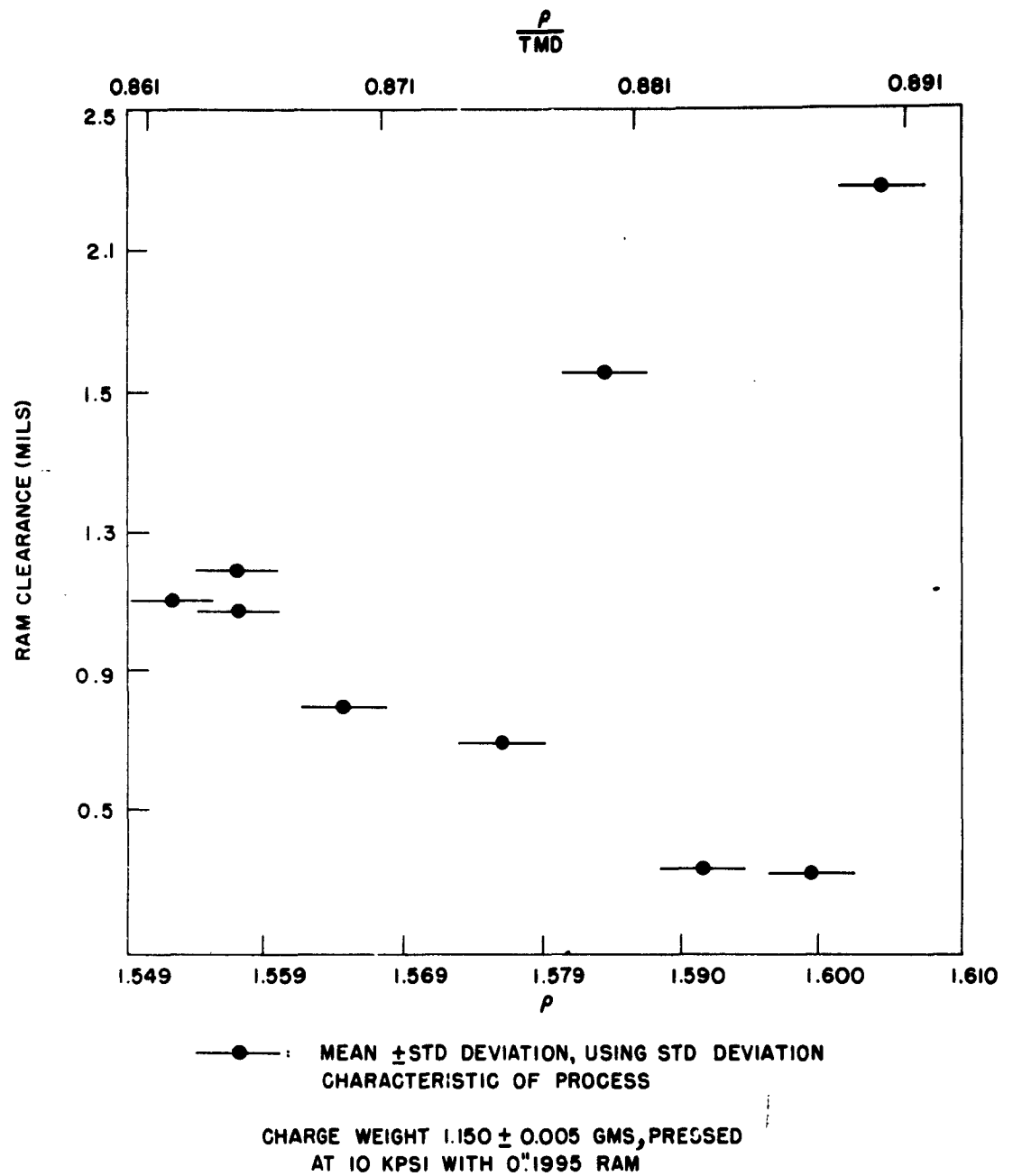
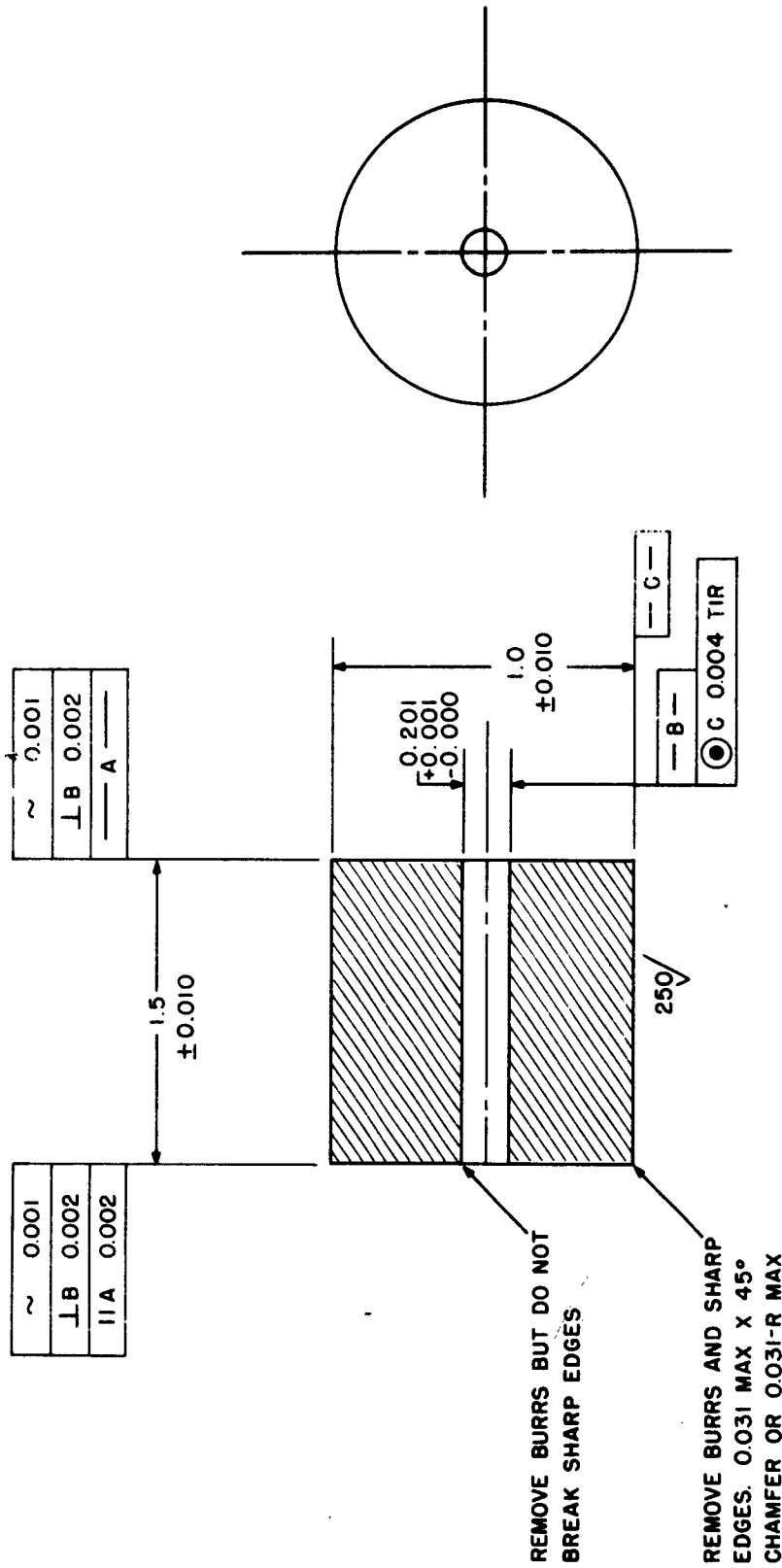


FIG. 19 EFFECT OF RAM CLEARANCE ON CHARGE DENSITY



- NOTES:
1. $63/$ ALL OVER EXCEPT AS NOTED.
 2. REMOVE ALL CHIPS AND FOREIGN MATERIAL. A THIN FILM OF OIL IS PERMISSIBLE.
 3. PACKAGE COMPLETED PARTS BETWEEN LAYERS OF CARDBOARD TO PROTECT $63/$ FINISHED SURFACES.
 4. DIMENSIONS IN INCHES.

FIG. 20 DONOR BODY DETAILS

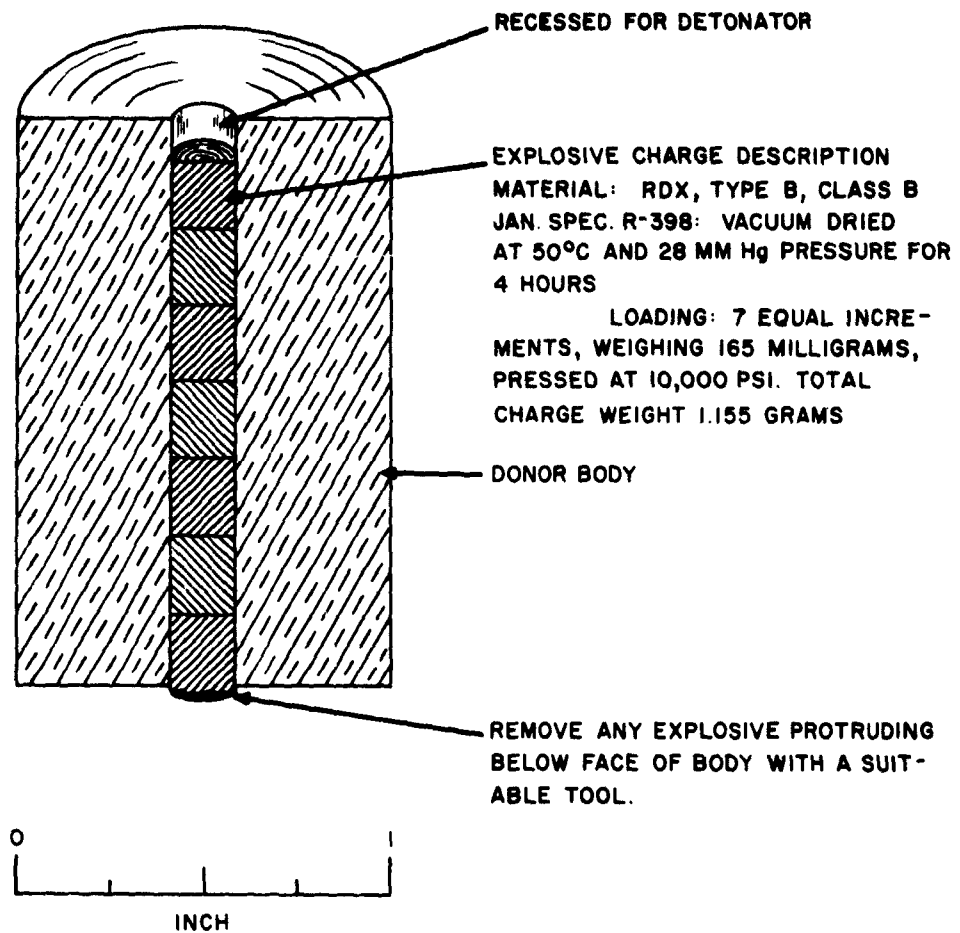


FIG 21 DONOR LOADING DETAILS

conditions had to be determined to about ± 4 milligrams. Modern balances of the automatic, single-pan, constant-load type permitted individual determinations at the rate of one a minute. Two main types of error were encountered; misreading of dial and vernier, and transposition of numbers. The most economical approach to this problem (a problem which could be reduced but not eliminated by training and practice) was to require re-weighing in all instances.

40. The final step in controlling the quality of the donor was the output test. Before the sample was taken, the entire production lot was arranged in random fashion. The first 5 or 10% in the sequence was fired against type "D" steel dent blocks. The requirement for steel dent output was that the mean dent should fall between 62-1/2 and 65 mils and the standard deviation should not exceed 2 mils.

ACCEPTOR LOADING INFORMATION

41. In the interests of economy and efficiency, the acceptor has been made as near as possible like the donor. In general the information in the previous section (in particular paragraphs 35, 36, 37, 38, 39) either applies directly or as background. The same body is used either for donor or acceptor. The acceptor column length is controlled in a manner different from that for the donor because the body is loaded flush at each end rather than with a 0.1-inch recess at one end. The charge weight must therefore be adjusted for each explosive and consolidation pressure in order to fill the acceptor body. The acceptor is loaded with eight rather than seven increments. The explosive is usually dried in the same fashion as is the RDX for the donor (paragraph 37).

42. In order to maintain donor-to-acceptor spacing accuracy, and also to keep to a minimum the air in the gap, the input face of the acceptor (both charge and body) had to be flat within 2 mils and preferably 1 mil. (Similar restrictions applied to the output face of the donor). The output end of the acceptor had to be in direct contact with the steel dent block. It was impractical, if not impossible, to adjust each individual charge so that the final explosive column would just come flush under the ram. It was found that if just a little more than enough explosive was pressed in, a pellet was broken off and left in the loading tool funnel. The broken surface of the acceptor charge was usually concave. Thus, whether the acceptor was over or under loaded there was usually a slight void between the end of the acceptor charge and the steel block. This void, it was thought, could lead to reduced dent because of attenuation over the air space or to increased dent because of a shaped-charge

effect. For this reason a number of donors (a sufficient typification of most acceptor conditions) were loaded with recesses in the output face of various shapes -- irregular, spherical, and flat -- ranging up to 26 mils deep. No effect on output was detected up to 20 mils depth of recess.

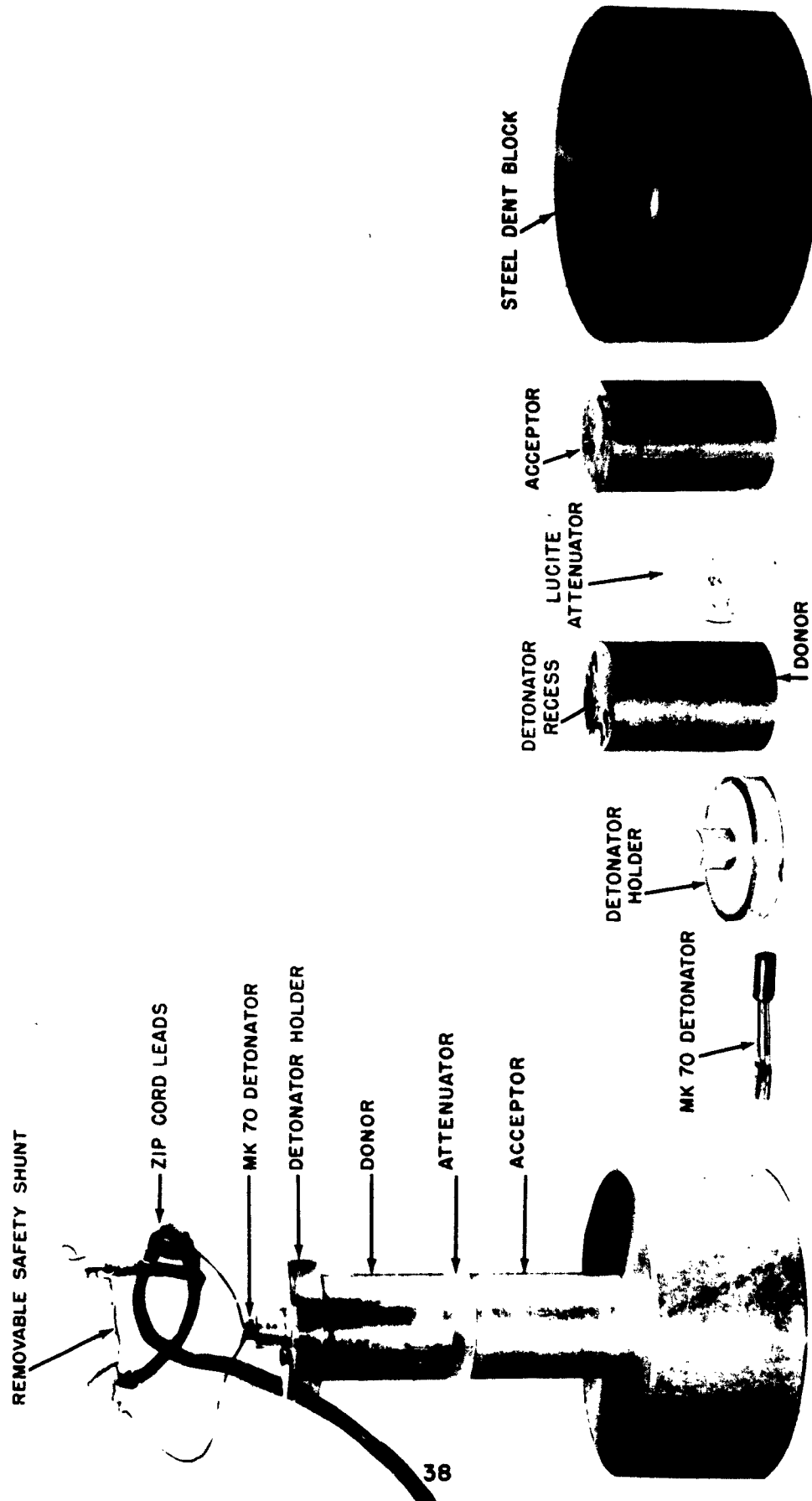
43. The control of acceptor charge density is much more critical than the control for the donor charge density. This is so because, in the range of 85 to 95% of voidless density, experience indicated that output was much less affected by density variations than was sensitivity. One index of density variability is the standard deviation of the individual readings. In most cases it was possible to keep the variation in charge density as measured by the standard deviation to less than 1/4% of T.M.D.. This was achieved by:

- a. Careful control of body dimensions, good maintenance of tools, and close supervision of loading operations, and
- b. Censoring of completed charges.

The censoring consists of selecting from 4 to 6 of the acceptors whose density falls farthest from the mean. Normally an equal number is taken of over-density and under-density. These samples are fired with zero gap in order to set the maximum output dent capabilities of the particular system under test. This is a legitimate selection process, even though not done in a random fashion, since it is assumed that the output is not sharply affected by density variation and since it is the intent of the experiment to fire samples of a given density or as close to the density as possible. The assignment of the remaining acceptors to the sensitivity test firing sequence should be done in a random fashion.

CONDUCTING THE REVISED SMALL SCALE GAP TEST

44. The experimental setup for the revised SSGT is shown in Figures 22 and 23. The donor, plastic attenuator, and acceptor were secured together by a peripheral wrap of Scotch Tape. The plastic detonator holder, which rested on top of the donor, was improvised from molded firing pin holders which are normally used for testing stab detonators. The Mk 70 Detonator was slipped into the 0.1-inch recessed end of the donor. A piece of masking tape was bridged over the whole assembly to prevent motion of the detonator and to keep the components of the assembly aligned on the dent block.



ASSEMBLED VIEW

FIG. 22 REVISED SMALL SCALE GAP TEST SETUP

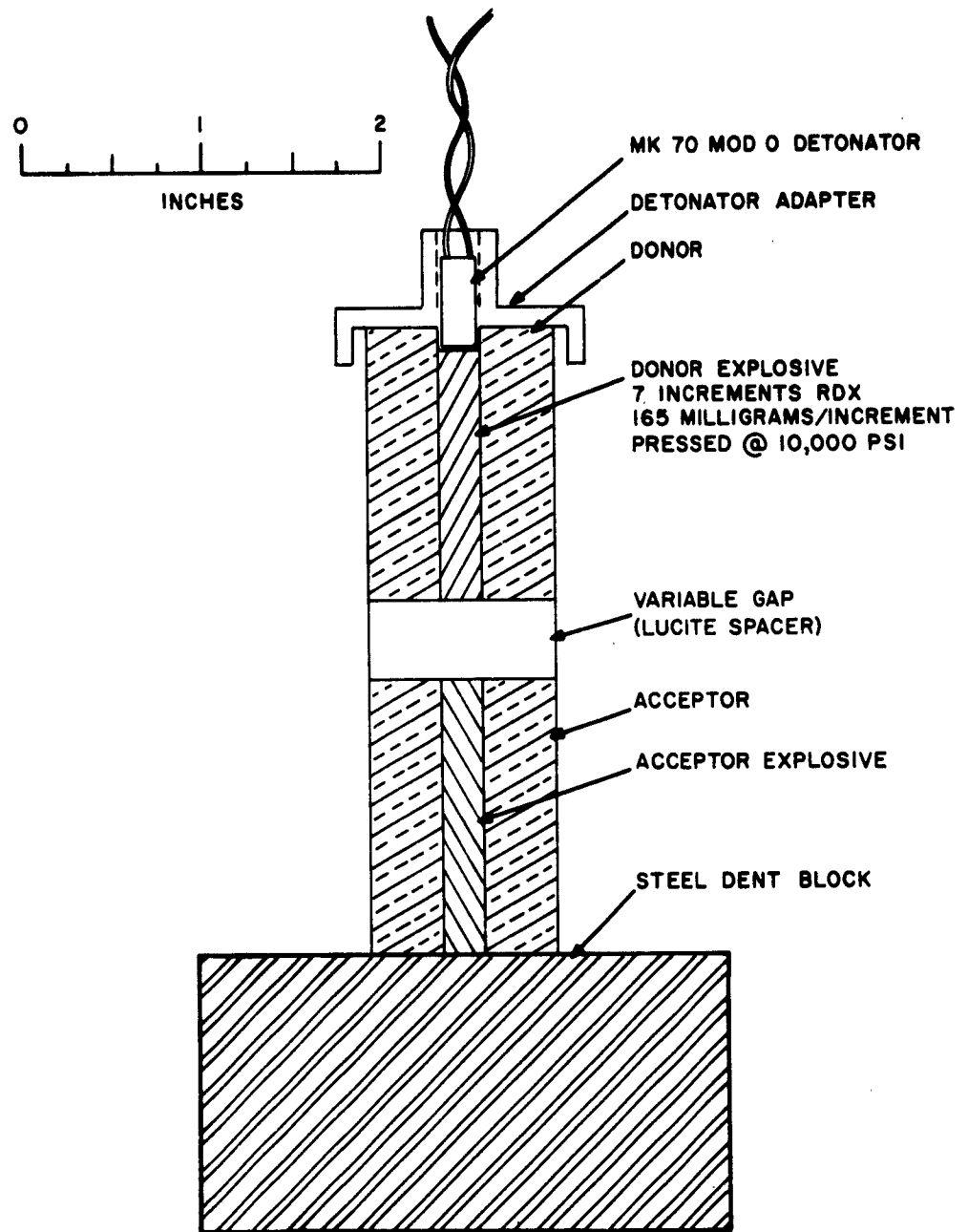


FIG. 23 DIAGRAM OF REVISED SSGT SETUP

45. Best results with circuit connections were obtained by setting up a labyrinth of heavy angle-iron and metal plate which housed a two-to three-foot length of household "zip" cord. As the end of the cord became too damaged to use, it was snipped off and a fresh portion pulled out of the labyrinth for use. Electro-mechanical interlocks were used. These were arranged so that no power could be applied to the detonator leads until the explosive charge was completely contained within the latched firing chamber.

46. A number of acceptors selected on the basis of density was first fired with no plastic attenuator. The average of the observed dents, \bar{D} , was taken as the dent capability of the particular test configuration. The dividing level (the criterion of fire) for assessing each shot was set at $0.5 \bar{D}$. Dent readings less than this level were interpreted as failures and greater than this level as fires. Comparison of this criterion with the shatter criterion (which was usually used on the original SSGT) showed that about the same answer would have been obtained in either case with conventional high energy explosives. If it were desired to introduce conservatism for reliability estimates, it would be possible to set the criterion of fire at a higher level such as $0.7 \bar{D}$ or $0.8 \bar{D}$. Similarly conservatism for estimates of systems-safety could use a criterion level of $0.3 \bar{D}$ or $0.2 \bar{D}$. In general, little change in the value of the mean explosive sensitivity \bar{X} will be caused by shifting the criterion from $0.2 \bar{D}$ to $0.8 \bar{D}$. The use of the steel dent block to assess acceptor response was felt to be of greatest value in that it should provide a consistent basis for judging explosives of widely differing brisance.

47. The Bruceton Sequential Stair-Step Test Plan⁴ is used normally with a 0.125 DBg step size. The comparison of the sensitivities of various explosive samples is more meaningful when some measure of the precision of the determination is also given. Measures of precision are s , the standard deviation of the reading; and s_m , the standard deviation of the mean. The s value, taken with the mean, is used to estimate some functioning level other than the mean. The s_m value, taken with the mean, is used to set fiducial (confidence) limits for the estimate of the mean. For instance:

- a. The 95% fiducial limits for the estimate of the population mean for the usual sample size ($m=22$) are approximately $(\bar{X} + 1.72 s_m \text{ to } \bar{X} - 1.72 s_m)$.

4. AMP Report No. 101.1R, SRG-P No. 40, "Statistical Analysis for a New Procedure in Sensitivity Experiments", July 1944.

- b. In order to compare two explosives or assess the effect of treatment on a particular explosive: compute fiducial limits ($\bar{X} + 1.4 s_m$ to $\bar{X} - 1.4 s_m$) for each of the two cases. If the limits touch or overlap, then it can be said at 95% confidence that no difference between the two populations has been demonstrated.

48. These statistical parameters are normally plotted simultaneously as shown in Figure 24. Specific examples related to explosive sensitivity are shown in Figures 25 and 26.

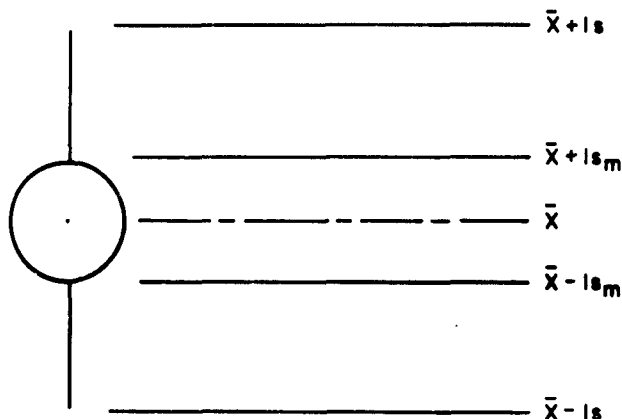


FIG. 24 CONVENTION FOR PRESENTATION
OF STATISTICAL PARAMETERS

The data may also be plotted as response versus initiation intensity in a "probability space". Straight lines, as shown in Figures 27 and 28, drawn for particular explosives in this space implies an assumption of a normally distributed response. The intersection of the line with the 50% response coordinate is of course the \bar{X} . The value of s is inversely related to the steepness of the line. This form of data plotting is of particular value in studies of explosive train safety and reliability.

PROOF OF THE PUDDING

49. A number of 2 component mixtures (RDX-Calcium Stearate) were compounded to provide a series of explosives of differing sensitivity. Figures 25 and 27 are plots of the sensitivities of these explosives as determined by the original SSGT. Figures 26 and 28 are the sensitivities of the same materials

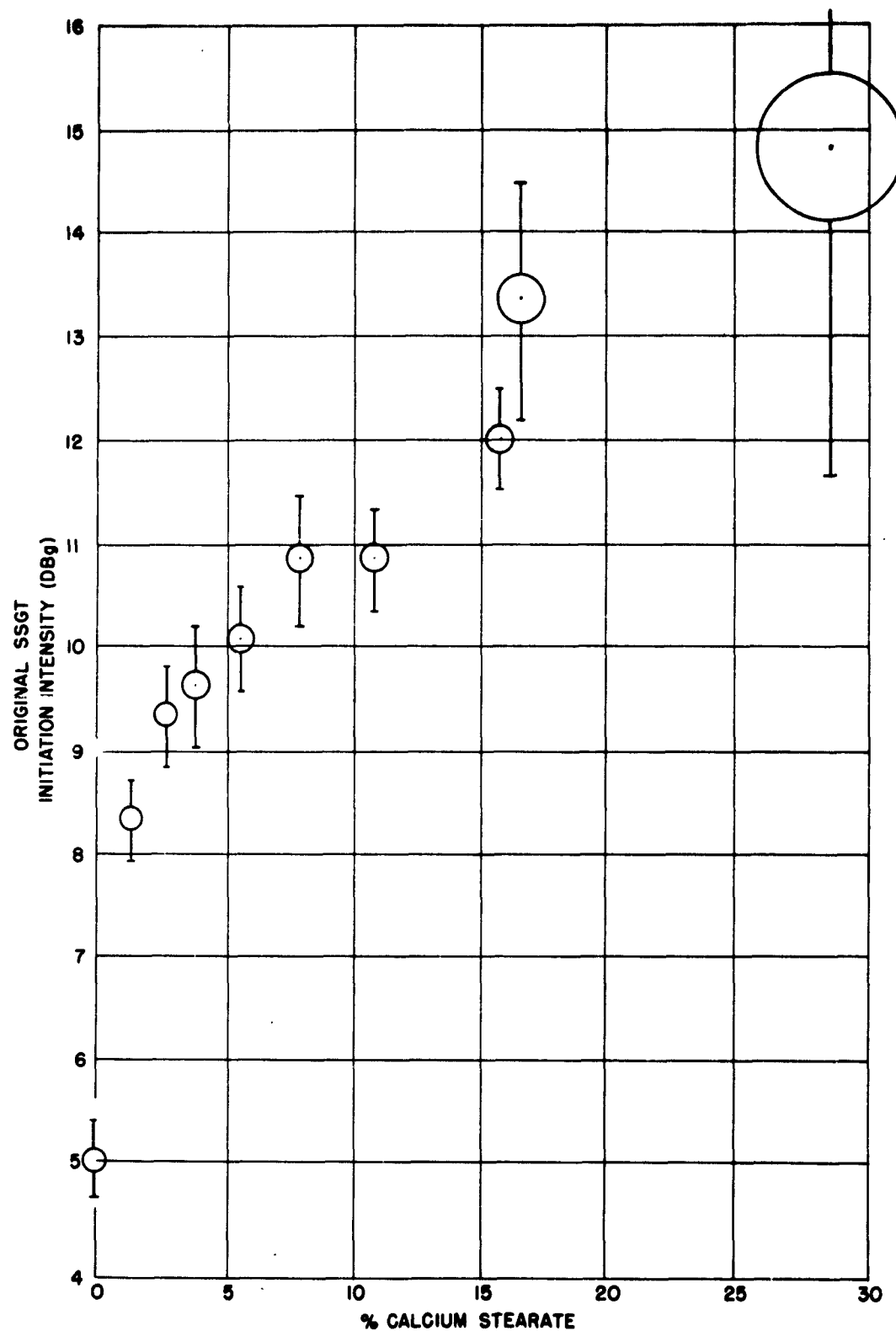


FIG. 25 ORIGINAL SSGT SENSITIVITY OF RDX-CALCIUM STEARATE MIXTURES

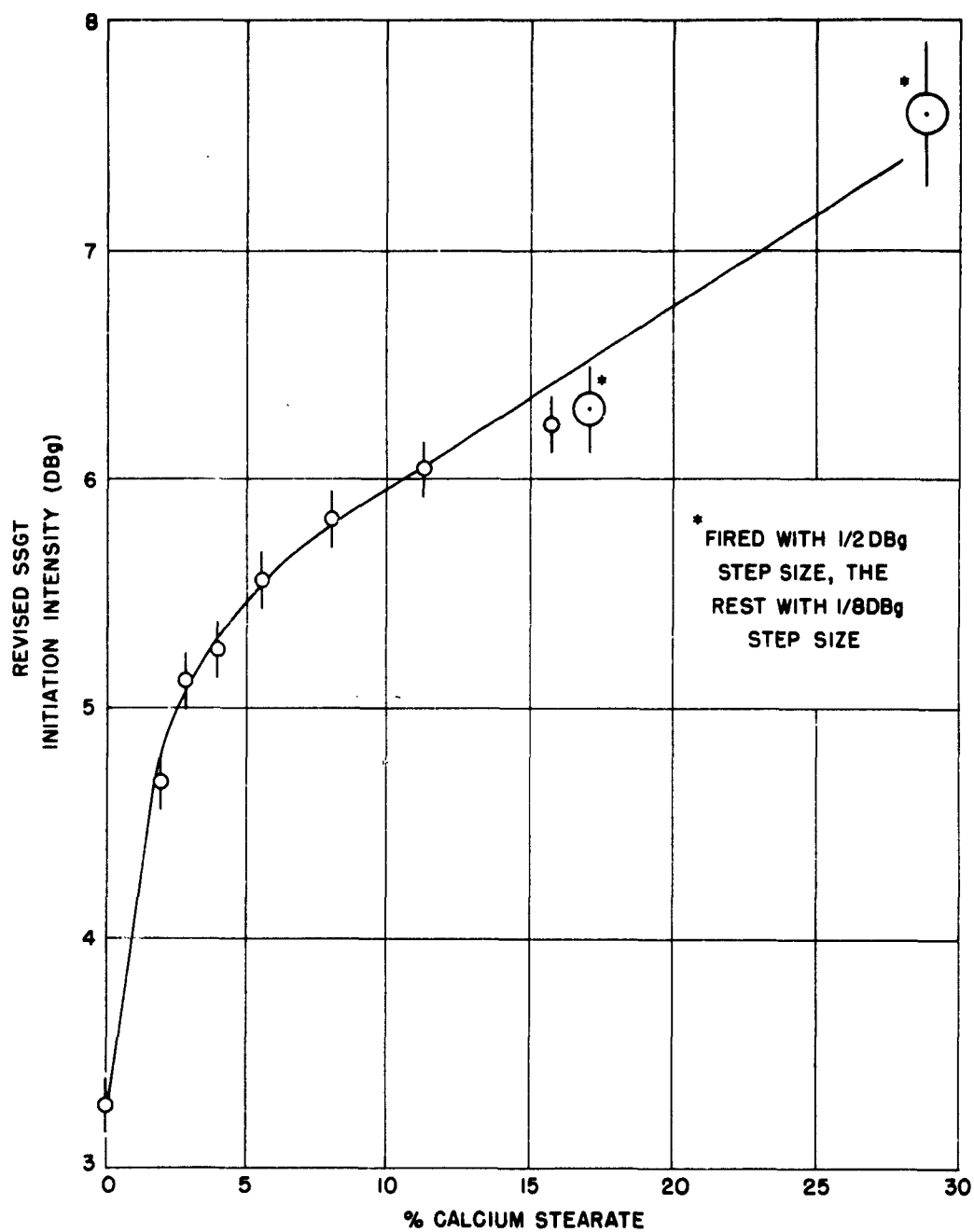


FIG. 26 REVISED SSGT SENSITIVITY OF RDX-CALCIUM STEARATE MIXTURES

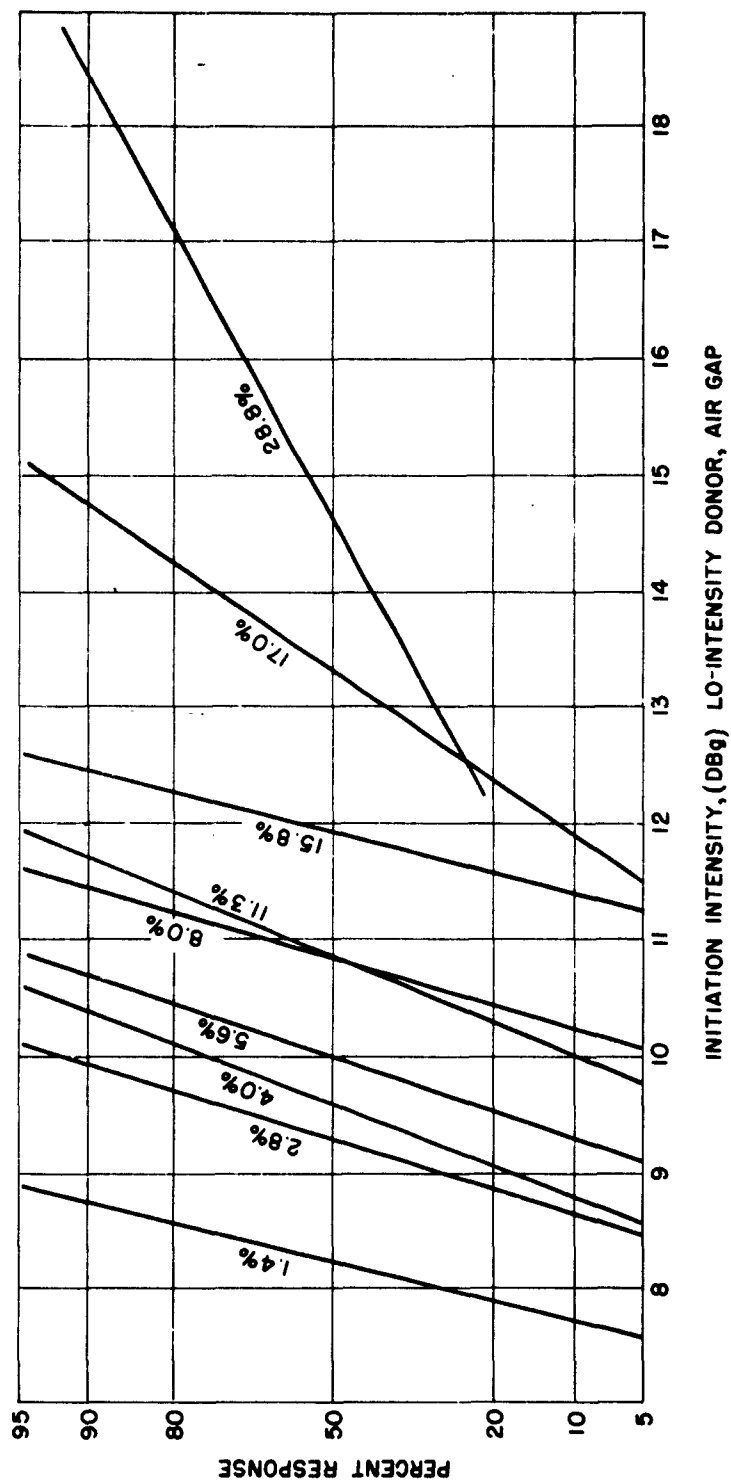


FIG. 27 ORIGINAL SSGT SENSITIVITY OF RDX-CALCIUM
STEARATE MIXTURES

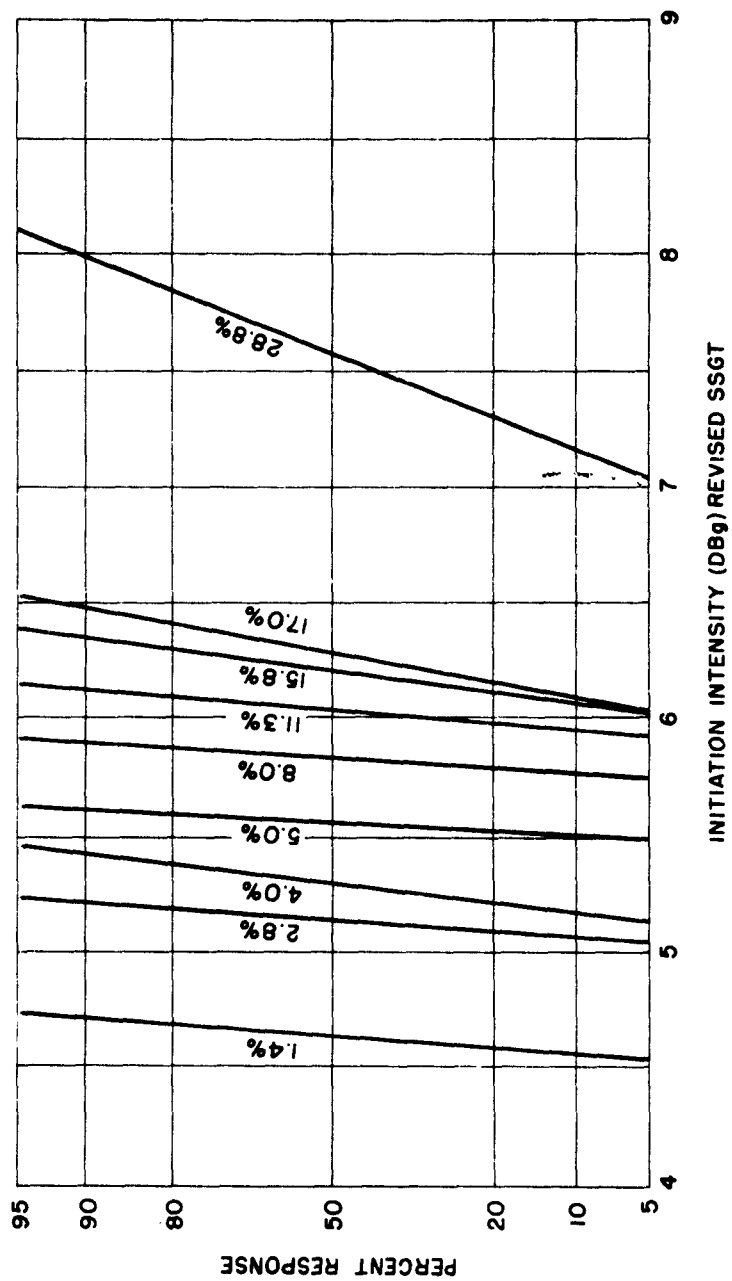


FIG. 28 REVISED SSGT SENSITIVITY OF RDX-CALCIUM STEARATE MIXTURES

NAVWEPS Report 7342

redetermined by the revised SSGT. From the data it was concluded that the revised SSGT increased resolution at least four-fold. This conclusion was based on the fact that although the spread of the mean sensitivities was cut about in half, the standard deviation was reduced by a factor of eight to ten.

50. In studies on conventional explosives some very interesting results were encountered. As can be seen in Figure 29, the sensitivity of pressed explosive charges may be very sharply affected by the charge density. It is possible that TNT (at 85% of voidless density) is more sensitive than RDX (at 95% of voidless density). The variability of density and of sensitivity is shown by diamond-shaped patterns caused by interconnecting the sensitivity \bar{X} 11s points with the appropriate density $\bar{\rho}$ 11s points.

CONCLUSIONS

51. The standardization of the SSGT has been accomplished with an increase of resolution of at least fourfold. This increase in resolution can be attributed to:

- a. Unusual care in control of charge loading parameters --- weight, dimensions, density.
- b. Use of a condensed medium rather than air in the gap.
- c. Use of the Steel Dent Test as the criterion of fire or fail.

52. Data have been obtained which afford interesting comparisons between the attenuation of three explosive systems with air and with lucite. These data plus the fact that a linear transformation seems to exist between the old and the new SSGT results suggest that the mechanisms of attenuation by the two media do not differ appreciably.

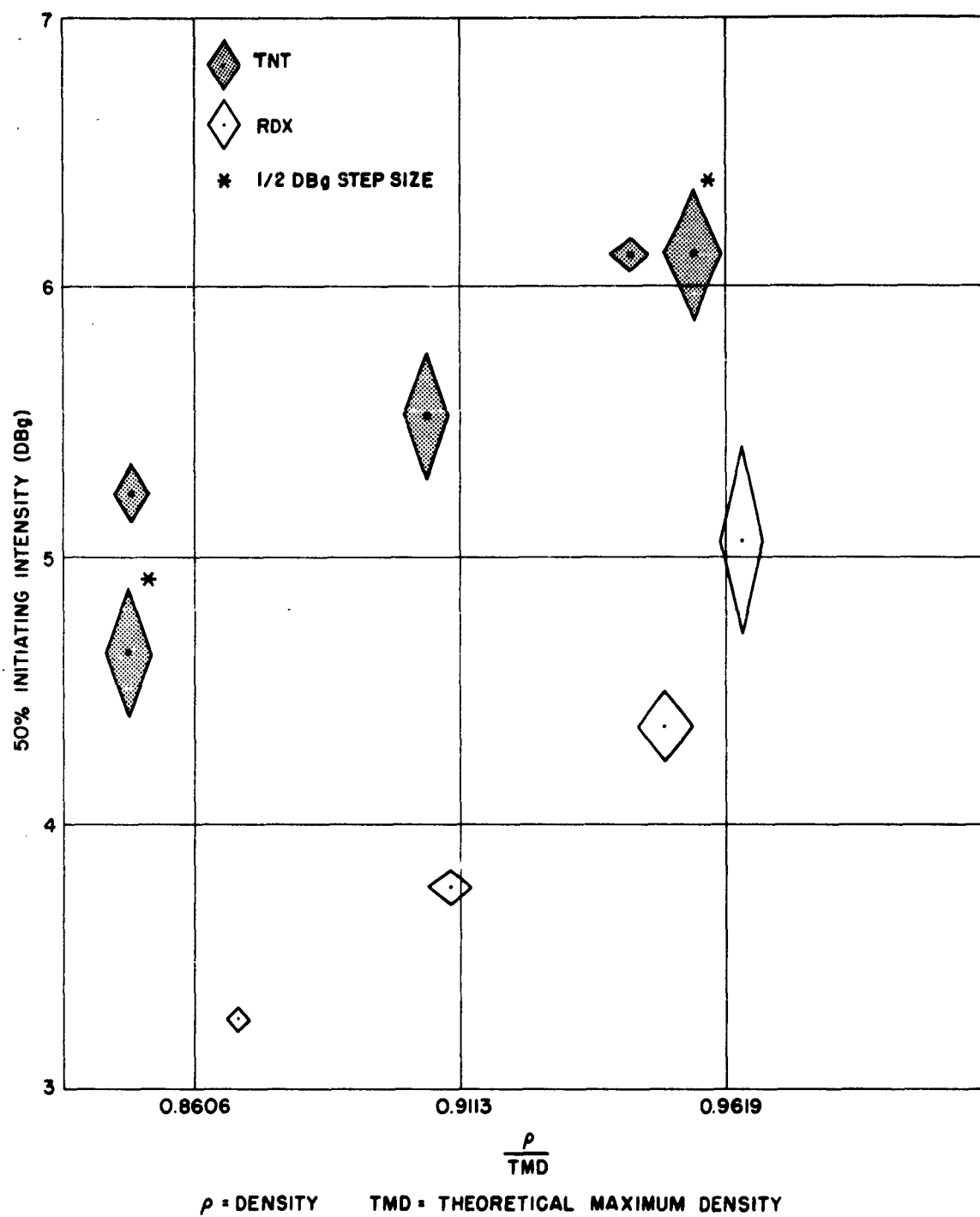


FIG. 29 EFFECT OF DENSITY ON SENSITIVITY

APPENDIX A

RESUME OF EARLY WORK ON THE SMALL SCALE GAP TESTS

1. R. Stresau and L. Starr at the Naval Ordnance Laboratory designed a test to study the fundamental relationships which govern the transfer of detonation between small confined explosive charges, such as detonators and leads. This test, the Small Scale Gap Test, is described in reference (a) along with results of investigations of several of the factors affecting the transfer of detonation from one charge to another. Various studies using the SSGT are reported in references (b), (c), (d), (e), (f), (g), and (h). The technique of this test is to determine with what probability an acceptor will be initiated by the transfer of detonation from a donor across an air gap. The gap across which this probability is fifty per cent is taken as the measure of the sensitivity of the acceptor explosive under these conditions. Both donor and acceptor charges are confined in brass cylinders with an outside diameter of 1.0 inch and a length of 1.0 inch. The material and dimensions are changed in order to study effects associated with these changes. The piece into which the donor explosive is loaded also has provision for an initiator plug. Thus the length of the donor explosive column is reduced to approximately one-half inch. Various diameters of the explosive column have been used. The most common values have been 0.10, 0.15, and 0.20 inch.

2. The determination of the fifty per cent point for transmission of detonation across the air gap is made by use of a Bruceton test in which the air gap is varied. The steps are spaced at equal logarithmic intervals with two consecutive steps differing by about ten per cent. In using this test, it is necessary to be able to classify the result of each trial as either a fire or a misfire. This involves the selection of some criterion by which one may make this decision. These criteria have been used: shatter, in which the acceptor must be shattered; expansion, in which the hole into which the explosive was loaded must be expanded to a predetermined amount; and burning, in which any trial in which the acceptor explosive is burned is considered a fire. It may be impossible to use some of these in certain variations of the test. Thus, if the explosive column diameter is small in comparison with the outer diameter of the container there will be no shattering even when the acceptor explosive is initiated high order and this criterion is not available for use.

3. The explosives to be tested are press loaded into the inert parts. The small size of the explosive charge makes explosive casting difficult. It is primarily a test of those explosives which are ordinarily used in leads and detonators, and are loaded by dry-powder-pressing.

4. Stresau and Starr, reference (a), investigated the relationship between the diameter of the donor and acceptor explosive columns and the size of the fifty per cent air gap. They found that the air gap increases with an increase in diameter of the donor explosive column. The acceptor diameter associated with the greatest air gap was one which was slightly smaller than the diameter of the donor being used to initiate the acceptor. As the acceptor diameter was increased or decreased from this value the air gap decreased. This result was explained in terms of radial losses of energy occurring in the acceptor explosive.

5. The effect of the density of the donor or acceptor explosive is also discussed in reference (a). In general, increasing the density of an explosive increases its output and decreases its sensitivity. The air gap will therefore increase as the density of the donor explosive is increased and decrease as the density of the acceptor explosive increases. Savitt, reference (b), showed that the effect of the density of the acceptor explosive upon the air gap, as measured in this test, is dependent upon the criterion of fire used. When a small expansion of the metal acceptor piece was used as a criterion, the air gap increased as the density of the acceptor explosive was reduced down to the lowest practicable densities. When a shatter of the container was used as the criterion the results were quite similar to those attained with the expansion criterion for the higher densities but the air gap dropped quite sharply for the lower densities of the acceptor. This can be explained quite simply in terms of a combination of sensitivity and output. For the greater densities the output factor is unimportant and the two criteria give similar results. For the low densities the acceptor explosive has its output so much reduced that the container is much less likely to be shattered. This causes the apparent sensitivity, as measured by the shatter criterion, to decrease with decreasing density. On the other hand the sensitivity, as measured by the expansion criterion, increases with decreasing density throughout the entire range of densities.

6. The effect which the confinement of the acceptor explosive has upon its sensitivity was investigated by Stresau and Starr. They found that copper and lead were equally efficient as confining media with steel much better and aluminum a poorer medium. Reference (c) reports further studies of the confinement afforded both acceptor and donor explosives. For the

acceptor, steel afforded the best confinement, copper was intermediate, and aluminum and sintered steel were the poorest. The gap for aluminum and sintered steel was about one third of that with steel confinement of the acceptor. Data for brass and aluminum confinement of tetryl, RDX, and desensitized RDX mixes are reported in reference (d). A more complete investigation was carried out by Savitt and reported in reference (e). Materials used for acceptor confinement included steel, brass, bronze, babbitt, zinc, magnesium, bakelite, and lucite. Effectiveness of these materials as confining media was approximately in the order as listed with several being equal to each other. The air gap measured with bakelite or lucite was only one-fifth that with steel. Savitt found that there was a close relation between the effectiveness of a material as a confining medium and a combination of its density and hardness.

7. Reference (c) reports results with lead azide donors and tetryl acceptors in which different particle size tetryl was used. Tetryl which was held on a number 35 sieve was somewhat less sensitive than that which passed through this sieve.

8. Several other forms of this test have been used from time to time. One variant is the use of a transverse displacement rather than an air gap. Stresau and Starr investigated the change in the probability of transfer of detonation from donor to acceptor when there was a transverse displacement of one with respect to the other. They found that the probability of transfer of detonation was sharply reduced when the transverse displacement became great enough so that the expanded hole of the fired donor no longer covered a part of the explosive in the unfired acceptor. Their results are reported in reference (a).

9. A considerable amount of work has been done using a metal barrier between the donor and acceptor either with or without an air gap in conjunction with this barrier. Reference (c) reports work with lead azide donors and tetryl acceptors separated by an aluminum barrier. These results are compared with data obtained when using an air gap as reported in reference (a). The thickness of the aluminum barrier is about two-thirds the size of the air gap. Reference (f) reports tests using a lead azide donor with either an RDX/wax or a tetryl acceptor and with different combinations of an air gap and steel barrier. These include a test with steel barrier without an air gap, and two tests with a steel barrier next to the donor followed by an air gap. In one of these the air gap was kept constant and the thickness of the steel barrier varied, in the other the thickness of the steel was kept constant and the air gap varied to find the fifty per cent points. Reference (d) reports tests made with the end of the donor covered by a piece of steel

0.006 inch thick. The acceptor explosive was tetryl, RDX, or a desensitized RDX mixture. The air gap across which detonation is transmitted fifty per cent of the time is on the order of twenty times as great when the end of the donor is covered with this steel as it is when the end of the donor is bare.

10. Some work has been done using an acceptor column which is shorter than one inch. Dimmock, reference (g), reports results of tests which were made with an acceptor one quarter of an inch in length. This reduction in length results in a saving of explosive which would be of advantage with a new material which may be available only in small quantities. However, it is open to the objection that the detonation in the acceptor may not have stabilized in such a short column. Savitt, in reference (b), has shown that under certain conditions it is possible for the acceptor explosive to be initiated with a low order reaction which does not develop into a detonation until more than one inch of travel. In these cases an acceptor one inch in length would be classed as a misfire whereas a longer acceptor would be considered a fire. The reverse situation is also observed to occur. Thus the results of the gap test are dependent upon the length of the acceptor column used. This difference is not very serious for acceptors one inch or more in length. However, for lengths as short as a quarter of an inch the effect may be much more pronounced.

11. The basic test is not adapted to the measurement of the sensitivity of liquid explosives. A variation, reported in reference (h), was designed by Savitt and used to measure the sensitivities of liquid TNT, Composition B, Pentolite, TNETB, and RDX/TNETB/Wax, 60/34/6. In this variation the acceptor was in the form of a brass cylinder of the same external dimensions as previously. In one end there was a hole 0.375 inch in diameter and 0.375 inch deep. The acceptor was placed in a vertical position and the liquid explosive poured into this hole. The donor explosive in this experiment was a column of RDX 0.200 inch in diameter. Initiation was through an enclosed air gap of variable length with a diameter of 0.300 inch. The results give the liquid explosives tested in the following order of decreasing sensitivity: Pentolite, TNETB, RDX/TNETB/Wax, with Composition B and TNT equally sensitive at the lower end of the scale.

12. Another modification was made in order to test the sensitivity of explosives at elevated temperatures. The metal acceptor was wrapped with wire to form a heating coil which was electrically insulated from the acceptor. Provision was made for inserting a thermocouple next to the explosive by drilling a small hole in one side of the acceptor body. Preliminary trials showed that, upon being heated, the explosive extruded from the ends of the loaded acceptor thus interfering with the

NAVWEPS Report 7342

determination of the air gap between the donor and acceptor. In order to prevent this extrusion the explosive was loaded into an aluminum cup which was then placed in the acceptor body. This was set up with the bottom end of the cup towards the donor. Placed in this position the bottom of the cup prevented the explosive from extruding into the air gap. The inside diameter of the aluminum cups used was 0.147 inch. Preliminary results (not published) indicated an increase in sensitivity of such materials as pressed TNT, Composition B, and RDX. Further work in this configuration was set aside in order to accomplish the revision of the SSGT as described in the main body of the present report.

NAVWEPS Report 7342

REFERENCES

for

APPENDIX A

- (a) NOLM 10577, "Some Studies of the Propagation of Detonation between Small Confined Explosive Charges", R. H. Stresau, Jr., L. E. Starr, Jr., 15 July 1950.
- (b) NAVORD Report 3753, "Some observations on the Growth of Detonations", Jacob Savitt, 25 August 1954, (Confidential).
- (c) NAVORD Report 2385, "Investigation of the Propagation of Detonation between Small Confined Explosives Charges", Progress Report, W. E. Dimmock, Jr., L. D. Hampton, L. E. Starr, Jr., 1 April 1952, (Confidential).
- (d) NAVORD Report 4320 "Sensitivity and Pelleting Characteristics of Certain Desensitized RDX Mixtures", L. D. Hampton, 25 June 1956, (Confidential).
- (e) NAVORD Report 2938, "Effect of Acceptor Explosive Confinement upon Acceptor Sensitivity", Jacob Savitt, 13 November 1953, (Confidential).
- (f) NAVORD Report 3551, "Comparative Sensitivity of Tetryl and of RDX/Wax Mixtures as Booster Explosives", L. D. Hampton, 14 October 1953, (Confidential).
- (g) NAVORD Report 2494, "A Small Scale Gap Sensitivity Test", W. E. Dimmock, Jr., 2 July 1952, (Confidential).
- (h) NAVORD Report 2997, "A Sensitivity Test for Castable Liquid Explosives Including Results for Some New Materials", Jacobs Savitt, 22 October 1953, (Confidential).

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